SHARING TACIT DESIGN KNOWLEDGE IN A DISTRIBUTED DESIGN ENVIRONMENT

A Dissertation

by

JEONG-HAN WOO

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2005

Major Subject: Architecture

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Chair of Committee, Mark Clayton
Committee Members, Christopher Ellis
Benito Flores
Robert Johnson
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ABSTRACT

Sharing Tacit Design Knowledge in a Distributed

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Chair of Advisory Committee: Dr. Mark Clayton

Throughout the life-cycle of a design project, architects rely heavily on their tacit design knowledge to support design decisions. Tacit knowledge is highly personal and implicit. As such, it encompasses expertise, intuitive understanding, and professional insight formed as a result of experience. Due to its implicit nature, tacit design knowledge is typically shared only among colleagues who work in the same office through face-to-face interactions. With emerging Computer-Mediated Communication (CMC) technologies, designers face new opportunities for capturing and reusing tacit design knowledge. However, there is no accepted CMC strategy for sharing tacit design knowledge in the Architecture, Engineering, and Construction (AEC) industry.

This research investigates the impact of tacit design knowledge on design performance in a distributed design environment supported by CMC software. The software was developed and tested in three design studios in which design students sought advice from experts in remote locations. It provides tools for showing images, such as drawings and

renderings, and for engaging in a written dialogue (chat session). The written and graphic artifacts of the conversation are stored in a Web-accessible database.

The chat sessions included the identification, clarification, and explanation of real problems. Dialogue records provide evidence of a significant influence upon the students’ approach to conceptual design. Content analysis of the comments from the experts provides qualitative evidence for the software’s effectiveness. The participants shared past experience, professional recommendations, and intuitive expectations. In follow-up surveys, most participants reported that their experience with the software was very enjoyable and the software is well-designed to support sharing of design knowledge.

This research also suggests that tacit design knowledge may be confidently captured and shared through careful strategic implementation of CMC technology in a distributed design environment. Demographic and attitudinal surveys of the participants suggest that enabling factors for sharing tacit design knowledge include knowledge sharing attitude, just-in-time expertise matching, and timing of the communication.

Dedicated to the Lord, my parents, and my wife In Sun, who supported me throughout this entire venture

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CHAPTER I

INTRODUCTION

This chapter introduces the research by establishing the context and motivation, stating general questions for investigation, and revealing a deductive chain that led to the method. It also provides a guide to subsequent chapters.

1.1 Overview

This research investigates the idea of Computer-Mediated Communication (CMC) strategies to share and reuse tacit design knowledge in a distributed design environment. A review of literatures led to a theoretical model for the exchange of tacit design knowledge in a distributed design environment. A software prototype was devised to operationalize the theoretical model. Three case studies were conducted using the software to validate the theoretical model and gain insight into what occurs when design instructors purposely use CMC technologies to help architecture students attain specific instructional objectives. The case studies then provided evidence that tacit design knowledge can be shared and reused by using chat-based CMC strategies.

In the three cases, chat sessions were arranged between students and design critics external to the school.

This dissertation follows the style of *Journal of Planning Education and Research*.

The online chat was useful in sharing professional recommendations, intuitive expectations, and past experiences. The participants easily identified problems and solutions on the design projects, thus developed enhanced conceptual design. The design critics conveyed tacit design knowledge that was integral to the students' projects and was incorporated into the final drawings. Finally, the initial theoretical model was modified and extended as a theoretical model for design knowledge sharing process.

The research findings presented in this dissertation increase our level of understanding about the implications of the exchange of tacit design knowledge in a distributed design environment. The results show that the use of synchronous chat sessions positively influenced design performance by sharing and reusing tacit design knowledge. The answers from the surveys also indicate that the students' perception regarding the software is also very positive. Most students commented that they would consider using the software for sharing design knowledge in their next design studio.

1.2 Definition: Tacit Knowledge

Human knowledge can be classified into two types: tacit and explicit. Tacit knowledge is highly personal (Polanyi 1966), implicit (Reber 1993), context-specific (Sternberg et al. 2000), and unstructured knowledge. As such, it encompasses expertise, understanding, or professional insight formed as a result of experience. Another clarifying definition of tacit knowledge by Nonaka and Takeuchi (1995) asserts that tacit knowledge is the implicit form of human knowledge that includes cognitive skills, mental models, and technical skills. Explicit knowledge, on the other hand, refers to codified knowledge that is transmittable in formal, systematic language.

Because tacit knowledge is hard to formalize, write down, and communicate, tacit knowledge is deeply embedded in employees or organizations, and not always readily apparent (Nonaka and Takeuchi 1995). Due to its implicit nature, tacit knowledge is often shared using face-to-face meeting, demonstration, or learn-by-doing strategies requiring the physical presence of knowledge holders. However, some kinds of tacit knowledge could be accessible and articulated by the use of languages or codes (Ambrosini and Bowman 2001).

1.3 Tacit Design Knowledge in the Architecture, Engineering, and Construction (AEC) Industry

Because of the orientation toward unique and complicated projects, much knowledge of architects is experience-based and tacit. Considering that the knowledge needs in a project are dynamic, depending on the task to be performed, it is hard to develop a strategy for addressing these needs.

The AEC industry has gradually realized the value of capturing, storing, and reusing architects' design knowledge, both explicit and tacit. Sophisticated design problems are often solved by highly educated, experienced professionals. Architectural firms also assume experienced architects already possess extensive tacit knowledge for specific types of projects. Therefore, architects may encounter a situation that they have never experienced before and heavily rely on their tacit design knowledge to support design decision (Dixon 2000).

The tacit knowledge of architects has tremendous value if combined into one body of knowledge and shared with the right people at the right time. Schön (1983) convincingly demonstrated that experts' tacit knowledge may give a firm a competitive advantage by improving its efficiency and expertise. Novice architects try to gain tacit design knowledge through real experience or receiving instructions from experienced architects and begin to extend the web of design knowledge. Therefore, to achieve greatness, architectural firms strive to hire good architects with in-depth design knowledge and expertise. Ron Skaggs, Chairman and Past CEO of HKS, has stated that the employee is HKS' greatest resource (Skaggs 2002).

Current architectural design process has been described as a multi-participatory distributed design environment (Huang 1999) in which architects bring their own expertise to a project from remote locations. In a large architectural firm, work is sometimes duplicated because people are unaware of each other's work in remote locations. Consider a senior architect in a Dallas, TX, office who previously conducted several office building projects and a novice architect in a Miami, FL, branch office who is developing an office building design for the same client. These people could share extensive information if they were aware of one another's work and connected at the right time.

As the AEC industry becomes more competitive, architects may feel that they need more expertise and knowledge. Architects should support each other by sharing vital design knowledge to produce a better design solution. Skaggs (2002) also says that HKS has been looking for a knowledge sharing strategy that will facilitate the exchange of design expertise between design teams. The firms' main concern is how to hire great people and apply their architectural expertise on the projects at the right time.

Due to its implicit nature, tacit design knowledge is typically shared only among colleagues who work in the same office through face-to-face interactions. One way to share tacit design knowledge is to encourage architects to engage in more informal conversations as a form of "Communities of Practices." Some research shows us how experienced architects share their knowledge and experiences with apprentices through a form of storytelling and communities of practice (Brown and Duguid 1991; Schön 1983). The essence of informal conversations is a cooperative attitude that fosters collaborative work on projects. Participants can share and synchronize information and design knowledge among themselves.

1.4 CMC Technologies in a Distributed Design Environment

With the emergence of CMC (Computer-Mediated Communication) technologies, there are new opportunities for architects to share and reuse tacit design knowledge. The information systems of an architectural firm can easily support CMC tools beyond the mere exchange of electronic drawings or documents.

However, there is no consensus for a best CMC strategy for managing tacit design knowledge in the AEC industry. The typical strategy for knowledge management is to make knowledge explicit and store it as computer software and databases. Some authors (Hansen et al. 1999) have pointed out that IT (Information Technology) usefulness is limited to the transfer of explicit knowledge only. Chiti Ho (2002), Chief Technology Officer of 3D/International, also said in an informal discussion that the use of IT solutions influences the communication of explicit information only. The emphasis on IT may compromise the effective use of tacit knowledge; furthermore, experts' tacit knowledge could be wasted and ignored. A systematic way of capturing and reusing tacit knowledge may be crucial to preserving and enhancing the competence of a large distributed firm.

1.5 Research Problems

Tacit design knowledge, although acknowledged to be important to AEC firms, has not been confidently shared or captured through CMC technologies. A few design research efforts have been conducted on various aspects of CMC in the architectural profession

(Gabriel and Mahar 1999; Kvan and Candy 2000). However, these studies have rarely focused on the impact of tacit knowledge on the design artifact. The usability of CMC technologies has rarely been demonstrated empirically. Therefore, there is a need for empirical research to fully investigate the potential of CMC technologies and enrich understanding of how experts can reuse tacit knowledge in a distributed design environment.

However, there is no research that provides empirical advice on how to implement CMC technologies for the AEC industry. The existing strategies for managing, interpreting, and applying tacit knowledge on a project have failed to provide adequate value and thus have not been widely adopted. This study may guide the development of an appropriate use of tacit knowledge for architectural practitioners.

1.6 Contemporary IT for Distributed Knowledge Sharing

The difficulties in sharing tacit knowledge may be more serious in large geographically dispersed AEC firms. Reuse of tacit knowledge from design in construction and operations has a further barrier in the transition of authority and responsibility from designer to contractor to owner to occupant (Johnson and Clayton 1998). Some of the existing literature has shown that there are organizations that are beginning to use Intranet or VPN (Virtual Private Network) to support tacit knowledge sharing (Malhotra 2000). Messaging software, such as IBM Lotus Notes™, has been used as a collaboration tool to quickly share relevant knowledge when people need it by providing a place for online discussions and information sharing within organizational boundaries. Video conferencing software, such as Microsoft NetMeeting™, has been also used for online meetings.

1.7 Research Objectives

The primary goal of this research is to establish a theoretical foundation for clarifying the contribution of experts' tacit design knowledge and improving access, reuse, and documentation of tacit knowledge in a distributed design environment. Prototype software was developed to operationalize the proposed theoretical framework. The software implements an online, interactive chat tool with a database to store conversations. This research elaborates the concepts of design knowledge sharing in a distributed design environment by making close empirical observations in architectural design studios. Figure 1.1 shows the concepts of tacit design knowledge sharing by using IDEF0 (Integration Definition for Function Model) diagram. This model describes the exchange of tacit design knowledge that typically occurs on a face-to-face basis.

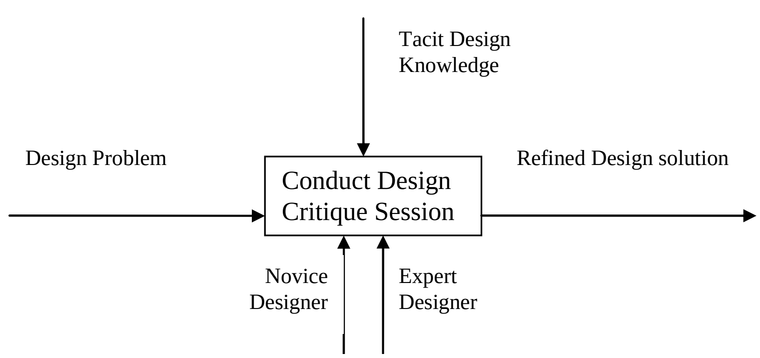


Figure 1.1 IDEF0 diagram of tacit design knowledge sharing

The secondary purpose of this study is to explore the impact of tacit design knowledge that has been captured and shared using the prototype software. Specifically, the research investigates the potential of chat-based software to assist designers in the exchange of tacit design knowledge and directing knowledge seekers to design experts who have the relevant tacit design knowledge that may be needed.

The software was tested in realistic design situations where design students sought a high degree of expertise and advice from experts in remote locations. Quantitative and qualitative observations of the use of the software provide evidence to find whether the software can assist in sharing, capturing, and reusing tacit design knowledge.

This research also determines whether the increase of tacit knowledge sharing achieved by the software could positively influence students' design performance. Expert designers may therefore be a richer source of new ideas and alternative perspectives. This research is significant because it may show that tacit knowledge strategy is appropriate for improving works in architectural firms through the exchange of tacit knowledge and is also vital for improving the quality of students' design work as well.

1.8 Research Questions

The specific objectives and corresponding research questions of this research are to:

1) Describe and implement prototype software which can assist in documenting and reusing experts' tacit knowledge.

<u>Research Question 1: What is the theoretical basis for exchanging and disseminating tacit knowledge in distributed architectural design environment?</u>

Evidence

1. Published opinion and fact that provides well-argued theory.

<u>Research Question 2: Does the software assist in capturing and sharing experts' tacit knowledge?</u>

Evidence

1. Working software that implements the proposed theory.
2. Opinion of the adequacy of the software, collected by using a questionnaire and students' feedback.
3. Examination of chat transcripts captured by the software to determine if they suggest exchange of tacit knowledge.

2) Observe the effect of tacit knowledge sharing as implemented by the software on the students' design artifacts.

<u>Research Question 3: Is tacit knowledge shared through online conversations evident in student design artifacts?</u>

Evidence

1. Relationship between dialogues and resulting design artifacts.

   a. Content analysis of dialogue transcripts that are recorded through chat sessions.

b. Identification of change between initial designs and designs after design chat session.

<u>Research Question 4: What are the factors that influence the effective use of the software?</u>

Evidence

1. Content analysis of dialogue transcripts that is recorded through chat sessions for knowledge acquisition/learning attitudes.
2. Analysis and criticism of design artifacts that exhibit the effects of tacit knowledge sharing.
3. Demographic profiles of participants.

CHAPTER II

LITERATURE REVIEW

There are many years of research conducted by a significant number of individuals that help establish a context and theoretical framework for software in support of tacit knowledge dissemination in architectural design. The literature review is organized into the following major sections: theories of tacit knowledge, the current status of knowledge management in the AEC industry, design knowledge in architecture, knowledge mapping, CMC, media synchronicity theory, and relevant research methodologies. Each section presents the theoretical foundation for the research as well as methodological consideration. The chapter then proposes a theoretical model that focuses on the exchange of tacit design knowledge in a distributed design environment.

2.1 Theories of Tacit Knowledge

Tacit knowledge is the intangible form of human knowledge. Michael Polanyi (1966) presented the first theory concerning tacit knowledge in his book, *Tacit Dimension*. He is the first person who began to draw a distinction between explicit and tacit knowledge. Polanyi describes tacit knowledge as “very personal knowledge” constructed in a social context. He also asserts that tacit knowledge cannot be expressed in languages as he says “We can know more than we can tell.”

Since then, Nonaka and Takeuchi (1995) recognized the importance of tacit knowledge and tried to demonstrate how to transfer personal tacit knowledge to shared mental models and technical skills. Numerous studies have demonstrated the importance of tacit knowledge in real-world work performance (Table 2.1).

Table 2.1 Tacit knowledge vs. explicit knowledge

Author	Explicit Dimension	Tacit Dimension
Polanyi 1966	Explicit Knowledge	Tacit Knowledge
Schön 1983	Not Available	Reflection-in-Action Drawing back talk
Reber 1993	Conscious Learning	Unconscious Learning
Sachs 1995	Organizational View	Activity-Oriented View
Hansen et al. 1999	Codification Strategy	Personalization Strategy
Zack 1999	Integrative Architecture	Interactive Architecture
Nakane and Meza 2001	Not Available	“Ba” Framework
Ambrosini and Bowman 2001	Objectivity	Tacitness
Gilmour 2003	Publishing Model	Brokering Model
Kankanhalli et al. 2003	Repository Model	Network Model

In much of the literature and industry, tacit knowledge has been emphasized and recognized as an important strategic resource in the development of sustainable competitive advantage and firm growth (Baumard 1999; Nonaka and Takeuchi 1995; Porter 1985; Sternberg et al. 2000; Sveiby 1997). The research done by Sternberg et al. (2000) showed that much of the knowledge needed to succeed in real-world tasks is tacit.

Malhotra (2000) also insists that explicit knowledge typically lacks the context required to be truly useful to the knowledge seeker. Nevertheless, organizations find it difficult to fully benefit from this valuable asset, experts' tacit knowledge (Johannessen et al. 2001; Stenmark 2000).

The distinction between tacit and explicit knowledge has evolved from many different perspectives (Figure 2.1). Schön (1983) uses a terminology "reflection-in-action" to describe tacit knowledge sharing in a design studio. Reber (1993) developed the theory of implicit learning based on cognitive psychology principles. He empirically demonstrated that knowledge acquired during learning activities is unconscious and implicit. He also argued that implicitly-acquired knowledge is often partially accessible to consciousness as fragmentary rules to guide behavior. In business literatures, many researchers develop theoretical frameworks illustrating tacit knowledge sharing: Activity-oriented view (Sachs 1995), personalization strategy (Hansen et al. 1999), interactive architecture (Zack 1999), "Ba" framework (Nakane and Meza 2001), tacitness (Ambrosini and Bowman 2001), brokering model (Gilmour 2003), and network model (Kankanhalli et al. 2003). However, most researchers also stated that there is little empirical research investigating the relationships between tacit knowledge sharing and resulting performance improvement.

One attempt to measure the effectiveness of tacit knowledge was performed by Sternberg and his colleagues (Sternberg et al. 2000). Their goal was to show the contribution of tacit knowledge to successful performance and to establish a relationship between the possession of tacit knowledge and job performance. They found that tacit knowledge can be quantitatively measured by using a set of tests. Their method is drawn from the methods of measuring real-world competencies including the use of the critical incident techniques, simulations, and situational judgment tests. The critical incident technique is an approach that seeks to identify the behaviors associated with effective performance by conducting interviews or open-ended questionnaires. Simulations assess job behaviors by observing people in real job situations. Situational judgment tests assess expertise using a set of tests that asks the best or worst answers for a specific job situation. Their studies also indicate that an individual's level of tacit knowledge is related to the individual's both job and school performance. Specifically, they assert that tacit knowledge can be a source of highly effective performance in the workplace. They also pointed out that the efficacy of tacit knowledge depends on effective acquisition and utilization.

According to the theory of organizational knowledge creation (Nonaka and Takeuchi 1995), the key to knowledge creation lies in the mobilization and conversion of tacit knowledge to explicit knowledge as shown in "The Knowledge Spiral" (Figure 2.1). The model introduces four modes of knowledge conversion: socialization, externalization, combination, and internalization. They point out that innovative change emerges through the interaction of tacit and explicit knowledge. Such interaction is different from a mere combination of discrete pieces of explicit information. This model is adopted as the foundation for the theoretical development for this research.

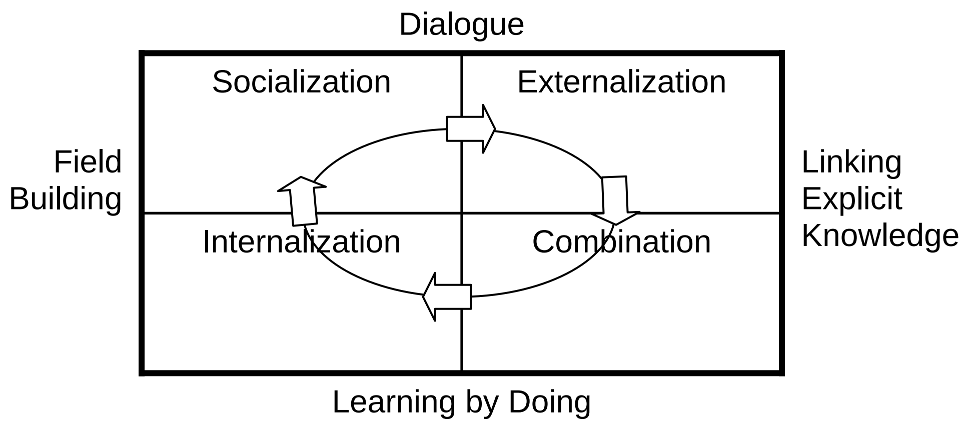


Figure 2.1 Knowledge spiral (Nonaka and Takeuchi 1995)

Converting tacit knowledge to explicit often fails because of low awareness of tacit knowledge and the necessity to make it explicit (Stenmark 2000). One of the most extensive research agenda of converting tacit knowledge into explicit forms is expert systems. The original purpose of expert system is to simulate high-level human expertise. Theoretically, expert systems should produce intelligent decisions in every situation. Expert systems are often difficult to extend and enhance once the system is fielded. The knowledge-based system works well only if the system contains enough knowledge from human experts. Feigenbaum (1992) describes the shortcoming of expert systems as “brittleness” and “isolation.” Researchers in expert systems are beginning to develop the concepts of interoperability of expert systems in order to connect expert systems in a geographically dispersed environment.

Herschel et al. (2001) argue that converting tacit knowledge to explicit is often time consuming and problematic. Sveiby (1997) also says that knowledge becomes static when tacit knowledge is made explicit through language. This is why tacit knowledge sharing is generally limited to locating experts with the knowledge and encouraging knowledge seekers to communicate (Davenport and Prusak 1998).

There is a range of different degrees of tacitness as shown in Figure 2.2. Ambrosini and Bowman (2001) point out that deeply ingrained tacit knowledge (Type A) is not accessible by the use of languages or codes. Highly tacit knowledge could be only accessed using face-to-face meeting, demonstration, or learn-by-doing strategies requiring the physical presence of knowledge holders. In geographically dispersed environments, tacit knowledge sharing is subsequently limited to Type B Knowledge (imperfectly articulated tacit skills) and Type C Knowledge (articulated tacit skills) (Figure 2.2).

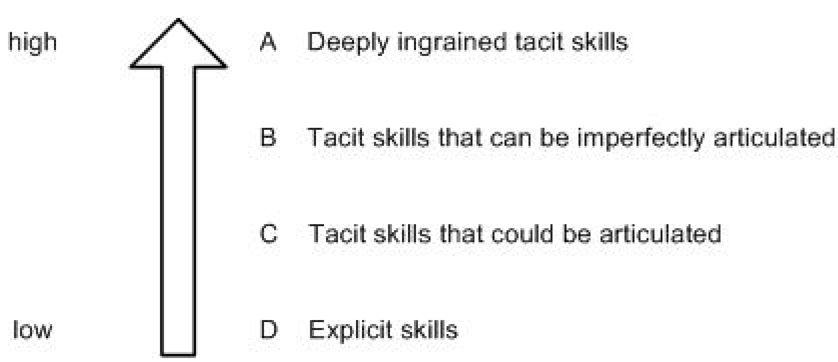


Figure 2.2 Degree of tacit knowledge (Ambrosini and Bowman 2001)

Several researchers point out that tacit knowledge is hard to formalize, write down, and communicate (Nonaka and Takeuchi 1995; Polanyi 1966). One of the more successful initiatives for sharing tacit knowledge is Communities of Practice (Brown and Duguid 1991). These communities are designed to build a wider network of knowledgeable experts who would like to work together to learn and solve complex problems just-in-time. In general, they operate informally through meetings, video-conferences, or email communications to exchange tacit knowledge and work practices on topics of interest to the members. The communities also can manage the explicit database of explicit knowledge.

There are only a few empirical research studies of tacit and explicit knowledge utilization. Experimental research conducted by Herschel et al. (2001) focuses on the comparison of tacit and explicit knowledge representation methods. They created two films that differ in how information was structured. The first film uses free narrative forms while the second film uses the same narratives but uses explicit information structures in the film. The contents of the films are identical. Their results show that tacit knowledge representation methods excel at sharing knowledge, but their effectiveness critically depends on whether the recall process is explicitly structured.

Somech and Bogler (1999) use survey research to investigate the relationship between tacit knowledge and student learning and achievement. The survey asked questions about a tacit knowledge scale and biographical information. The tacit knowledge scale develops an item list that represents behaviors associated with successful performance relative to academic life. The results reveal that students who scored high on the tacit knowledge scale achieved higher academic grades than students who scored low on the tacit knowledge scale.

2.2 Current Knowledge Management in the AEC Industry

The AEC (Architecture, Engineering and Construction) industry has been successful at collecting and storing explicit information databases as represented in design manuals and handbooks, such as *Architectural Graphic Standards* or *Timesaver Standards*. For many decades, those books have accumulated numerous amount of architectural design knowledge and have been the fundamental design reference for many generations of architects and designers.

As such, the typical strategy for knowledge management is to make knowledge explicit and store it as computer software and databases. However, the industry may be poor at tacit knowledge retrieval and sharing. Fruchter and Demian (2002) said that this strategy often failed because of the following factors: overhead required to capture; limited knowledge; poor IT infrastructure of organizations. Additionally, there are numerous obstacles for knowledge management strategies resulting from the articulation of tacit knowledge.

The primary reason that most knowledge-based systems are not well integrated into the AEC process is that it is difficult for project managers to assess the applicability of knowledge-based system to the AEC processes (Levitt and Kunz 1985). Within the context of rapidly changing technologies and processes, the existing knowledge-based system no longer seems capable of meeting the increasingly complex knowledge demands in the industry. Although the technical capabilities of knowledge-based systems are expanding, they still fall short of applicability to the AEC processes they are designated to support.

More recently, ASP (Application Service Providers) have offered a variety of unique types of on-line collaboration systems to centralize and store project-specific knowledge that is mainly explicit, such as project drawings, schedules, RFIs, change orders, and other reports. The systems also provide tacit knowledge resource via memos, discussion forums, and chat functions. The main purpose of the systems is not to communicate knowledge, but rather to codify, store, and disseminate knowledge. These types of systems are provided by companies such as Citadon.com (www.citadon.com), Buzzsaw.com (www.buzzsaw.com), and Constructware.com (www.constructware.com). These companies provide numerous white papers and reports that contribute insight into the use of explicit knowledge sharing through Internet tools. Constructware (2005) asserts that the biggest problem in the AEC industry is the poor communication between the companies involved in the design and construction projects. Other research suggests that AEC companies using web-based communication and collaboration tools improve their communication process among project partners without delay and with little difficulty (Wesek et al. 2000). Those systems enable construction partners to collaborate online across long distances. Therefore, the AEC industry is gaining benefits from sharing explicit knowledge by using online collaboration tools (Bridges 1997). Furthermore, those tools enable AEC organizations to deliver construction projects much faster by shortening communication, mailing, and traveling time (Roe and Phair 1999).

Some AEC companies have tried to implement a “Lesson Learned” system to record personal tacit experiences (Rogus 2001). However, the systems require extensive efforts to record tacit experiences. Consequently, AEC professionals still find it difficult to access core knowledge for highly knowledge-intensive AEC activities.

2.3 Tacit Design Knowledge in Architecture

Some researchers in the field of architecture have rigorously studied the importance of tacit knowledge sharing in architectural design environments. The researchers use different terminologies for tacit knowledge: visual analogy (Casakin and Goldschmidt 1999), episodic knowledge (Visser 1995), reflective practice (Valkenburg and Dorst 1998), personal knowledge, expert knowledge (Cross and Cross 1995), and strategic knowledge (Kvan and Candy 2000). However, these research projects repeatedly are focused on the local exchange of tacit knowledge through face-to-face interactions.

Visser (1995) used the term ‘episodic knowledge’. He argued that most knowledge used in problem solving is episodic and extremely abstract based on experience. He examined the use of episodic knowledge in a local design studio by analyzing the protocol in search for the use of episodic knowledge that is used to solve the design problem. His study showed that the use of episodic knowledge plays an important role in design problem solving by exploiting the experience of other people and reusing problem-solving elements. He finally suggested developing a design assistant tool to aid in accessing episodic knowledge in a more systematic way.

Based on Schön’s theory of reflective practice that derived largely from individual design activities, Valkenburg and Dorst (1998) investigated the use of tacit knowledge in team design activities. The notion of reflective practice emphasizes the use of action-oriented, implicit knowledge for design professionals. Their study uses two design teams to describe and compare two different team design activities. This comparison strengthens Schön’s theory by revealing the occurrence of reflective practice in team design activities.

Casakin and Goldschmidt (1999) described the benefit of accessing relevant, prior knowledge through ‘visual analogy’ to solve new design problems. ‘Visual analogy’ is an explicit graphical representation of tacit knowledge. Their results indicated that the use of visual analogy improves the quality of design outcomes from the novice designers.

Schön (1983) convincingly demonstrates that experts' tacit design knowledge is a very important resource in the architectural profession. He defined architectural design processes as reflective practice and explored the traditions of the architectural studio to investigate how architectural students learn from instructors in a design studio. He also observed the learning process of architectural design in a studio setting from the beginning of the semester to the final review. Through in-depth description, he found two forms of the learning process, “learn-by-doing” and “reflection-in-action”. In a design studio setting, instructors usually tell and demonstrate their design theories and skills, and students listen and imitate. As a result Schön (1983) points out that design studio and professional mentoring are the mechanism for sharing tacit knowledge and importing expertise.

Suwa et al. (1998) stressed the importance of tacit knowledge in the design profession, especially in the educational sense. They studied designers' cognitive actions associated with freehand sketches. The protocol analysis revealed that freehand sketches represent designers' cognitive process and facilitate problem-solving that is based on tacit knowledge.

Cross and Cross (1995) observed the teamwork experiment of the Delft Protocols Workshop, with a particular focus on design activity as a social process. They conclude that the knowledge sharing process of design significantly influences the quality of design. They also insist that design methodology should address the design process as a social process that professional colleagues interact to share expert knowledge.

Jeffrey Huang (1999) studied knowledge sharing in distributed design environments. Throughout 60 interviews and observations of designers involved in collaborative design, he analyzed the collaboration patterns among design participants and derived how these patterns change with the introduction of new collaborative media. One of the significant findings from his research is the relationship between knowledge sharing and innovative design. He asserts that knowledge required to make sound design decisions should be distributed and leveraged within organizational boundaries. He concludes that such knowledge sharing contributes to innovative design solutions and the actions of participants are more transparent and shared while the systems may reduce the costs of knowledge transfer.

2.4 Knowledge Mapping

A knowledge map is a knowledge “yellow pages” or a cleverly constructed database that points to knowledge but does not contain it (Davenport and Prusak 1998). Knowledge maps typically point to people as well as documents and databases to enable a person to find an appropriate knowledge source (Davenport and Prusak 1998). The benefit of a conventional knowledge map is to locate the holders of tacit knowledge and communicate with them when their expertise is needed rather than spending time with imperfect solutions or searching for explicitly documented knowledge. However, the static nature of most knowledge maps (Mertins et al. 2001) is an obstacle to disseminate tacit knowledge just-in-time. A static knowledge map could be enhanced by using CMC technologies to support easy additions and modifications to the map.

More recently, the concept of knowledge mapping has evolved to expert locator or the capability of searching through a set of biographies for an expert in a particular knowledge domain (Davenport and Prusak 1998). The purpose of expert locator is to find appropriate experts who hold enough knowledge in a situation.

Because the knowledge needs in AEC organizations are dynamic, Cheng and Kvan (2000) insisted that expertise matching can be more critical to successful virtual design studios than expensive high-tech equipment. Their finding justifies the application of knowledge mapping for sharing design knowledge in the AEC industry. However, these studies did not investigate the implementation of knowledge mapping in the AEC industry.

2.5 Computer-Mediated Communication

Due to the development of emerging CMC technologies and geographically dispersed business environments, the use of CMC has been inevitably accepted. Face-to-face meeting is now being recognized as too costly in terms of time and expense. A review of literature and theory supports the development of theoretically attractive software so that the concepts of tacit knowledge sharing can be operationalized in a distributed design environment.

CMC research has focused on the potential of various synchronous and asynchronous collaboration technologies to improve work performance (Herring 1996). The technologies include voice recognition, online conferencing, instant messaging, chat, blogging, and email. Several factors are significantly related to the success of CMC: participants' commitment, supporting environments, the reward of participation, and most importantly, volume of knowledge.

Spenser and Hiltz (2002) investigated the effect of synchronous chat in online courses based on the framework of media synchronicity theory (Dennis and Valacich 1999). Handel and Herbsleb (2002) reported an empirical study of a synchronous messaging application designed to support teamwork in the workplace. In the AEC industry, Al-Qawasmi (1999) explored the effectiveness of online collaboration technologies on architectural design performance.

In a distributed design environment, CMC provides an important medium by which architects can share their tacit knowledge in the form of dialogue. The primary communication channels for online tacit knowledge sharing are typically an online chat system or instant messaging (Ribak et al. 2002). Although the functionality of these two tools is widely adopted for entertainment purposes, several articles (Isaacs et al. 2002, Ribak et al. 2002) report cases where these tools successfully support knowledge sharing and informal communications within a large firm.

O'Hara and Brown (2001) also insisted that CMC technologies can at least support tacit knowledge sharing by encouraging conversation initiation. They point out that CMC can encourage more face-to-face interaction within a locally distributed organization. CMC can be used to schedule a telephone conversation or arrange a face-to-face meeting. It can be used to devise an agenda or document the information from a meeting. Kankanhalli et al. (2003) also says that CMC technology can support tacit knowledge sharing by providing one-to-one interaction.

Synchronous chat has been a CMC technology for interaction with entertaining purposes. It is beginning to be used in the work place. In the field of architecture, Kvan and Candy (2000) studied and argued that synchronous chat plays a significant role in the solution of collaborative design problems. One limitation of their research is the narrow observation of the design activities. Their research could not explore how the chat sessions improve the quality of design projects. Clearly, there is widespread curiosity regarding how to use CMC to facilitate tacit knowledge exchange in the AEC industry. Through the use of appropriate research methods, it is possible to achieve a thorough understanding of the exchange of tacit knowledge via CMC to improve design works.

2.6 Media Synchronicity Theory

Among many theories about the use of CMC, media synchronicity theory (Dennis and Valacich 1999) has been adapted for the theoretical basis of the chat-based software development in this research. This theory extended media richness theory (Daft et al. 1987) to provide a more reasonable justification for the use of new CMC technologies.

In media richness theory, face-to-face interaction has been recognized as the “richest” medium based on social presence theory. However, Dennis and Valacich (1999) claim that the use of communication media should be evaluated by the communication needs in a situation rather than “richness”. In their words:

> The richest medium is that which best provides the set of capabilities needed by the situation: the individuals, task, and social context within which they interact. Thus, concluding that face-to-face communication is the “richest” media is inappropriate.

They also insist that the productivity of a group task is improved if the media capabilities are synchronized with the participant’s communication needs. They also demonstrate that the synchronicity of CMC must be compatible with a group task for effective use. The synchronicity is defined by four media characteristics as follows: rehearsability, reprocessability, symbol variety, parallelism, and immediacy of feedback. Rehearsability is the ability to rehearse or reexamine messages before sending. Reprocessability is the ability to modify messages before sending. Symbol variety is the different ways of communication. Parallelism is the number of conversations that can happen at the same time. Table 2.2 shows a comparison between face-to-face and online chat based on the five characteristics.

Table 2.2 Synchronicity of communication mode (Dennis and Valacich 1999)

	Face-to-face	**Online Chat**	**The Software**
Immediacy of Feedback	High	Medium	Medium
Symbol Variety	Medium	Medium	High
Parallelism	Low	Medium	Medium
Rehearsability	Low	High	High
Reprocessability	Low	High	High

The characteristics of design communication have been described by a few design researchers (Gero and McNeil 1998; Schön 1983). Considering the task and the communication needs of the design studio, the communication in architectural design can be described as “reflective practice in situation” (Schön 1983). Design communication contains high level tacit design knowledge which requires in-depth cognitive process, rather than fast conveyance of the information. Therefore, design communication could be successfully served by a lower media synchronicity that has high rates of reprocessability and rehearsability.

Cheng and Kvan (2000) also demonstrated that online chat is a very effective CMC for sharing design knowledge in a distributed design environment. Gabriel and Maher (1999) defined online chat–based design communication as “talk by typing” in their research about virtual design studios. Their research showed that chat-based software in a distributed design environment can play a significant role. They concluded that chat-based design communication is equally effective as face-to-face meetings for design critiques even though there are some differences in the methods of conveyance.

Herring (1996) insisted that face-to face communication takes longer time for in-depth knowledge sharing. Furthermore, the design communication in architectural design should accompany some kinds of visual aids since architects always tend to draw while they talk. So, parallelism is another important factor in design communication.

2.7 Relevant Research Methodologies

While there is clearly a widespread curiosity regarding how to use CMC for the exchange of tacit knowledge in the AEC industry, it is necessary to choose appropriate research methods to achieve more complete understanding of ways to implement CMC. A variety of research methods are relevant to this research: software usability testing, case study, protocol analysis, and content analysis.

2.7.1. Software Usability Testing

Since this research involves the development and testing of software, usability testing is very relevant. Neilson (1993) developed “discount usability engineering” methods and identified five basic attributes of usability testing: learnability, efficiency, memorability, error rate, and satisfaction. He also recommended considering multiple usability methods for gathering supplementary data, such as heuristic evaluation, observation, questionnaires, interviews, focus groups, logging actual uses, and user feedback. For this study, questionnaires, actual use logs, and user feedback are employed to measure users’ satisfaction and efficiency.

The majority of empirical research in design collaboration has observed professional practice and educational environments. Software prototyping is often used to solidify theories and test the theoretically justified software performance (Cheng and Kvan 2000; Jabi 2003). Statistical analysis of multiple interactions has been used to characterize how Web-based project management systems are used by architecture, planning and engineering teams (Laepple et al. 2005).

Although much research has conducted tests of software to support architectural design, there is a lack of concrete evidence to measure the beneficial effect of this software. Clayton et al. (1998) developed “Charrette Test Method” in which one compares performance using one set of tools to performance which uses another set of tools in a short, focused project. Their method provides strong empirical evidence about software effectiveness beyond mere usability. The Charrette Test Method increases reliability of the test method through the comparison of evidences from the other tests, such as worked examples, demonstrations, and multiple trials.

2.7.2 Case Studies

In instrumental case studies, a particular case is examined to provide insight into a phenomenon or to test a theory (Stake 1995). Case studies in CMC research typically test prototype software to examine the effectiveness of the proposed software. Handel and Herbsleb (2002) report the case study of 6 geographically dispersed work groups that used a synchronous messaging tool for 17 months. Spencer and Hiltz (2002) report the findings from a case study that used synchronous chat in online courses. They conducted participant observation, student surveys, and interviews over four semesters. Because this research posits the effects of a new kind of software, an intervention study is an appropriate form of research. Furthermore, an instrumental case study is an appropriate research method because the software's effects are likely to be subtle and cannot be validated statistically without many years of observations.

2.7.3 Protocol Analysis

Protocol analysis has been a popular research method to investigate the design process. In this method, researchers examine records of design sessions to investigate designers' cognitive and behavioral strategies (Gero and McNeill 1998). For example, the protocol studies of Schön (1983) analyze the design activities of design instructors interacting with students to validate the theory of reflection-in-action.

Protocol analysis may use the “think aloud” procedure that asks the participants to state all their thoughts so that the researcher can understand what they think. This method is still under debate as to validity since the “think aloud” method may interrupt the cognitive process of the participants. Typically, the protocol data are classified by a coding scheme that represents meaningful criteria for the research. The coding scheme to categorize the verbal records is often rich but unstructured. Coded data can be analyzed to discover meaningful patterns either by qualitative analysis or statistical analysis. This research adopts qualitative analysis to gain evidence for the software’s effectiveness.

In this research, the chat transcripts captured in a database are used as the protocols. The idea of using a chat transcript for data collection has rarely been tried. However, chat transcripts automatically record what the participants say during the experiment. Therefore, there is no interruption of cognitive process and little or no interference of the research into the exchange process.

2.7.4 Content Analysis

Ethnographical content analysis conducted by Schön (1983) and Cross and Cross (1995) are most relevant to the data analysis of this study. Their studies show that detailed observation enables systematic descriptions of designers' improvement resulting from experts' instruction.

Content analysis methods are divided into two categories: quantitative content analysis and ethnographic content analysis. Quantitative content analysis focuses on collecting quantitative data on various types of messages in documents or communication media and employing a coding scheme. Ethnographic content analysis utilizes the examination of document contents while considering the social interactions and cultural settings and frequently employs the use of qualitative analysis.

2.7.5 Design Evaluation

The aim of design methods research is to improve the design process by providing an understanding of certain design activities and suggesting new design processes. Numerous design studies measure design quality to determine the effectiveness of new design approaches. Research methods have been developed to conduct experiments that produce valid conclusions. These studies show how design quality can be measured using a variety of aspects.

Dorst and Cross (2001) evaluated industrial designers' work on a variety of aspects including creativity, aesthetics, technical aspects, ergonomics and business aspects by using five design teachers. Atman et al. (1999) studied the difference between freshman and senior engineering design processes by measuring design quality. They developed forty design constraints and criteria to assess design quality.

Casakin and Goldschmidt (1999) assessed the quality of design solutions using three volunteer judges-all experienced architects. The judgments were further verified by reliability analysis. Sancar (1996) investigated three different design approaches effects on “design relevant behavioral knowledge”, and then he evaluated students’ design product by using three design evaluators. The design evaluators were asked to judge studio projects based on these predetermined attributes: meeting functional requirements, supporting experiential quality, clarity of design concept, and design process.

2.8 Summary

Reviewing literature on theories of tacit knowledge, design knowledge, knowledge mapping, design research, and CMC (Computer-Mediated Communication) elaborates the theoretical perspectives of this research as illustrated in Figure 2.3. Literature on software usability testing, protocol analysis and design quality evaluation is also relevant to the methods used in this research. Review of these multidisciplinary research areas provides a theoretical and methodological foundation for this study.

Throughout the literature review, a recurring theme emerged substantially was the importance of tacit knowledge sharing in a collaborative work environment. A series of design research and CMC theory literature recognizes the challenges and potential of tacit design knowledge in a distributed design environment. However, little research has been conducted investigating how CMC helps the architectural design process. Previous studies could not clearly identify the impact of tacit design knowledge on design performance in a distributed design environment. And many of the studies merely conducted the narrow observations of the design activities. A comprehensive understanding of the impact of CMC on tacit knowledge sharing could be acquired by studying the whole design process from beginning to the end.

The most relevant theories for this research are represented in Figure 2.3 that combines and extends of the work of Davenport and Prusak (1998), Schön (1983), Sternberg et al. (2000), Nonaka and Takeuchi (1995), and Herring (1996). The theoretical model shows that knowledge sharing starts with the identification of an appropriate knowledge holder and involves the concept of knowledge mapping (Davenport and Prusak 1998). Socially constructed knowledge is created through socialization, and is a process of sharing experiences, which thereby create tacit knowledge such as shared mental models and technical skills (Nonaka and Takeuchi 1995). This process occurs without intention or awareness (Reber 1993). Reber (1993) also focused research on the phenomenon of acquiring tacit knowledge without intention or awareness. He called it "implicit learning".

The software for this research intends to help the "Socialization" process by performing the role of knowledge map and aiding communities of practices. As a result, job performance can be improved through the accessibility of socially constructed knowledge that is a form of practical intelligence (Stenberg et al. 2000). The theoretical model below was revised by formulating the research results at the conclusion of this research.

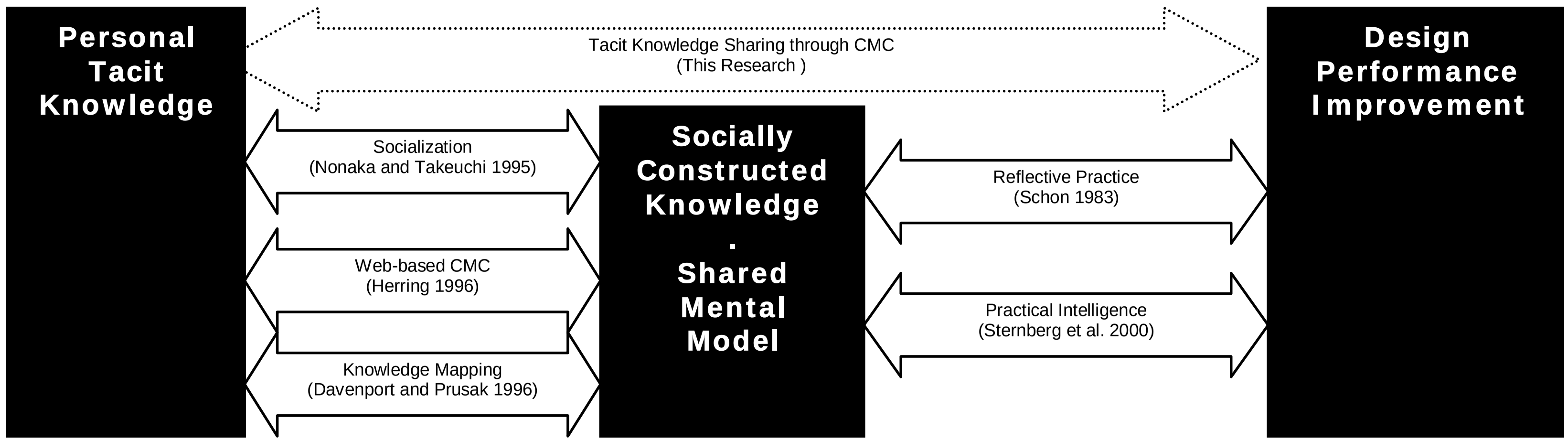


Figure 2.3 Relevant theories

CHAPTER III

RESEARCH METHODOLOGY

This chapter presents key methodological considerations that have influenced the data collection and analysis. Instrumental case study approach is as the most suitable method of inquiry for the research questions presented.

The general methods used in the studies were consistent throughout all three case studies. In all cases, a design problem was given to a group of participants, usually architectural design students, and they were asked to produce a design solution that meets the requirements of the design problem. Students consulted with experts as needed and desired. One case employed graduate students and the other two cases employed undergraduate students. More details of the specific research settings and instruments involved in each case study are discussed in the following chapters.

3.1 Philosophical Assumptions

The stance of this research is the post positivistic study. Post positivists assert that the goal of research is to continuously try to achieve the goal of obtaining absolute truth and maintaining objectivity, even though that goal can never be fully achieved. Therefore, post positivists emphasize the importance of multiple measures and observations and the need to use triangulation to build a better theory (Denzin and Lincoln 1994).

Instrumental case study approach is used in this research. Three case studies were selected to get deeper insight into research variables that operationalize a phenomenon. The method is useful in providing a description and understanding of what happens during the research period (as a basis for improving practice). An instrumental case study depends on formal observations and an in-depth data analysis.

The impact of tacit knowledge sharing cannot be judged by a single criterion due to the complexity of knowledge transfer processes. In case study research, it is important to employ multiple data sources drawn on the same phenomena (Stake 1995). Multiple data collection provides a richer picture from multiple perspectives. Based on this premise, data was collected and analyzed using qualitative and quantitative methods to enhance the validity of findings: content analysis, log files, frequency counts of dialogues, timestamps, simple statistics, and questionnaires. Quantitative data such as questionnaire, log files and counts of frequencies of the software use supplement qualitative observational data to triangulate evidence and produce valid conclusions.

3.2. Design of Trials

Three case studies were conducted as shown in Table 3.1

Table 3.1 Case comparison

	Case Study 1	Case Study 2	Case Study 3
Study Duration	1/2003 – 5/2003	3/2004 – 5/2004	6/2004 – 7/2004
Study goal	To validate research methods and collect data for preliminary data analysis	To test prototype software and learn how the software affects the exchange of tacit knowledge	To conduct further observation on the exchange of tacit design knowledge
Project Topic	NASA Crew Restraint System	Peckerwood Garden Development	Historic Bryan Downtown Development
Sample	3rd - 4th Year Undergraduate Students from 8 different schools	1st Year Graduate Students at TAMU	3rd Year Undergraduate Students at TAMU
Knowledge Holders	4 NASA Engineers	7 architects	1 local architect, 1 remote architect, 1 city staff
Communication Channels	PostDoc (Document repository) Volano Chat® Ver. 2.1	Physical Meeting Prototype Software Video Conference	Physical Meeting Prototype software

3.3 Sample

The sampling strategy used in this research is purposeful sampling with the logic of operational construct sampling. This strategy is widely used to gain understanding of real-world examples of particular theoretical constructs (Gall, Borg and Gall 1996).

Design studio students were purposely selected to participate as knowledge seekers in this study. After a difficult search, several student groups who met the following criteria were identified: instructor willing to allow student to use the prototype, instructor willing to invite design critic from the industry, students capable of producing electronic versions of the design artifacts, and students who can conduct online chats.

The software was tested in architectural design studios in which design students sought advice from design critics in remote locations. The design studio required students to address highly technical topics outside their area of previous education, such as sustainable construction, cost/constructability analysis, and landscape design.

Several informal interviews were conducted with architectural design studio instructors prior to the experiment to determine which instructors were willing to use the prototype software in their design studio. At the end of the interview, two design studio instructors agreed to allow their design studios to participate in this study. The characteristics of student participants are varied by design studio. Characteristic details of each group are described in the following chapters.

Several Informal interviews were also conducted with potential design critics during design critic chat sessions. A group of design critics who explicitly indicated that they want to participate in the chat sessions were selected and invited to participate as knowledge holders. The design critics selected for participation were very knowledgeable about the project topic, proficient computer users and familiar with online chat environments. Theoretical precedents (Schön 1983; Cross et al. 1996) support that the nature of behavioral characteristics is equivalent between architectural students and design professionals. When we investigate an architectural studio, we have a chance to observe the process of architectural designing (Schön 1983).

3.4 Focus of Observation

The focus of observation for this research is tacit knowledge sharing operated by the software in a design studio that is illustrated as the research variables in Figure 3.1. The unit of analysis is architectural students and design critics who participated in a design studio to solve a complex design problem. Students' behavior and the design products of their efforts were be observed.

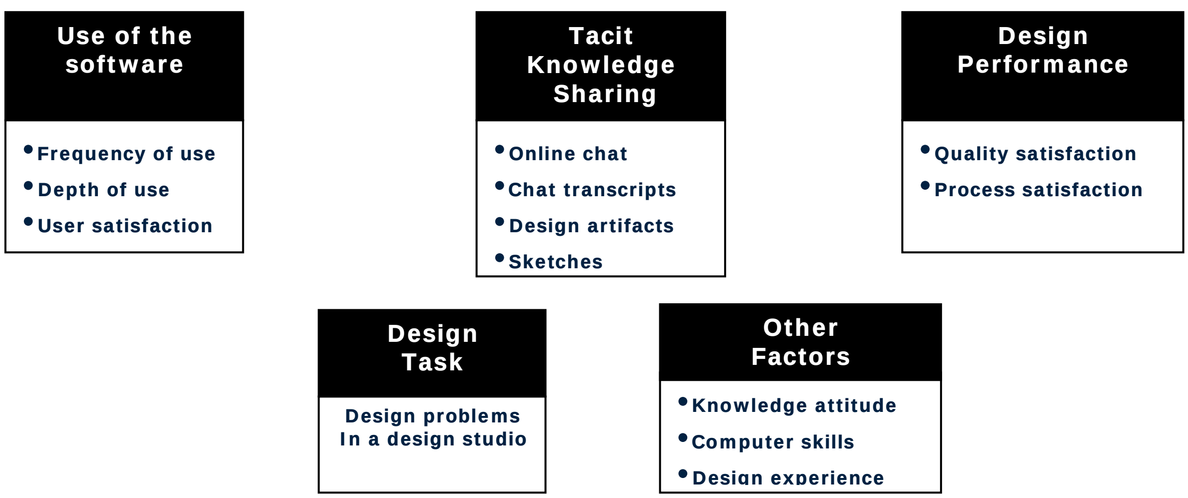


Figure 3.1 Research variables

3.5 Prototype Software

The prototype software was introduced into a typical design setting to alter the design processes and design products. The software is analogues to apparatus for research. This chapter describes the prototype software that was developed to operationalize tacit knowledge sharing in a distributed design environment. The prototype development is aimed at building tools for altering a typical process of design knowledge sharing, and embodies several theoretical foundations outlined in the previous chapters.

The prototype software is an interactive chat environment employing a visual display of design projects and is designed to investigate new methods of sharing tacit design knowledge. Those methods include locating, selecting, and communicating with the architects who have experience with similar projects. The two later case studies used the prototype software while the first case study used conventional chat software.

The software is a synchronous CMC system that has some added functionality of asynchronous CMC. The major functionality includes a chat room, a chat archive and a tool used to search through the archive for experts (Figure 3.2). The software implements an Internet-based chat environment enhanced by graphic and visualization tools that is supported by a database system and delivered through Web technology (Figure 3.3).

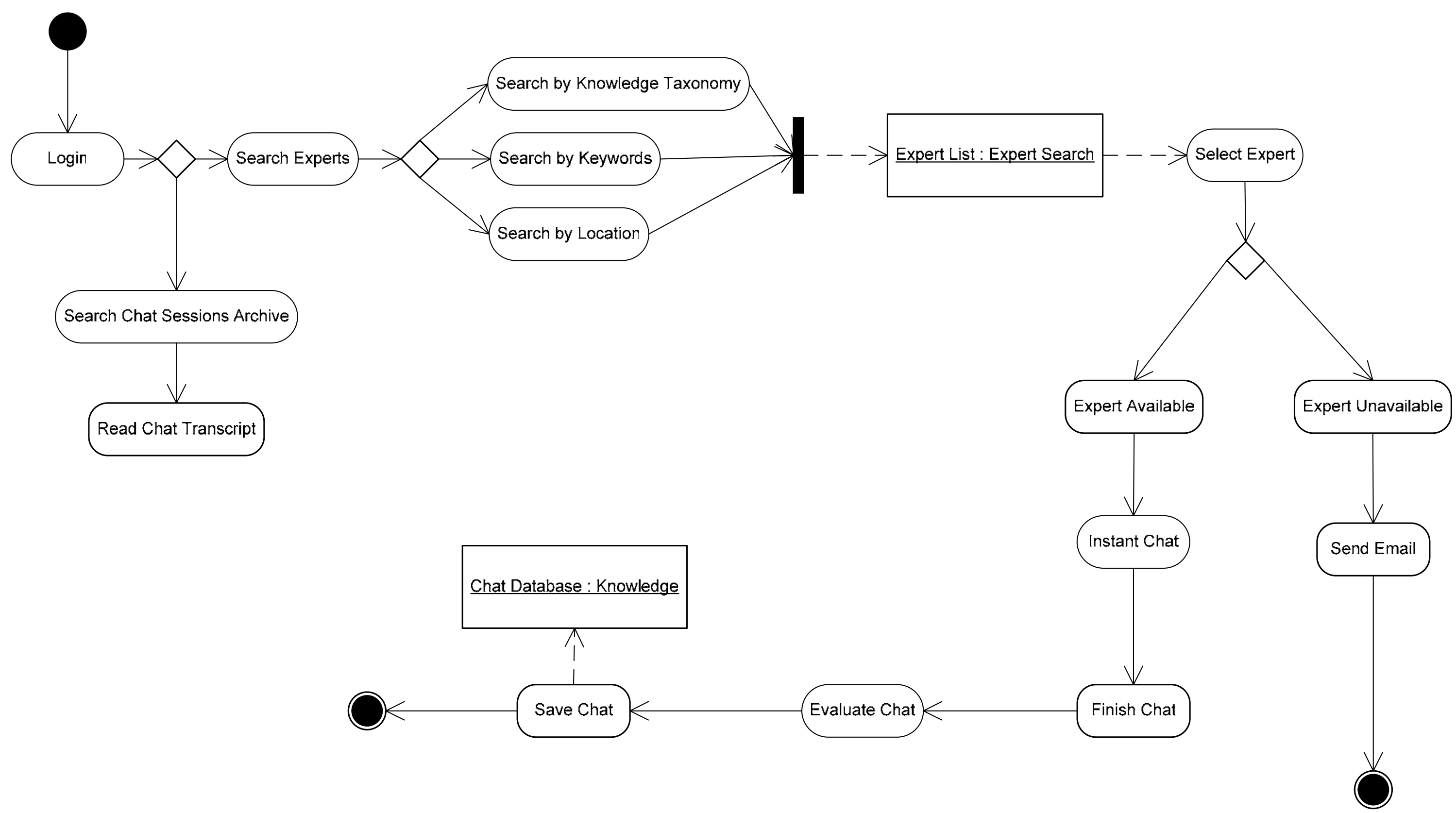


Figure 3.2 Activity diagram of the prototype software

After logging onto the software, students can search for an expert with the relevant tacit design knowledge and connect with them in real time by using instant messaging or synchronous chat. As a result, they can receive instantaneous tacit help from an expert who has recent experience with similar design projects. At the time of communication, experts' tacit knowledge may be transferred and applied in students' design processes. All of the dialogues are saved in a database as a record of tacit knowledge sharing and will be accessible for others who did not participate in the exchange at a later date to retrieve them for sharing the tacit knowledge that is conveyed in the dialogue. Additionally, a grading function enables the system to develop a sense of usefulness or reliability of experts on various design topics.

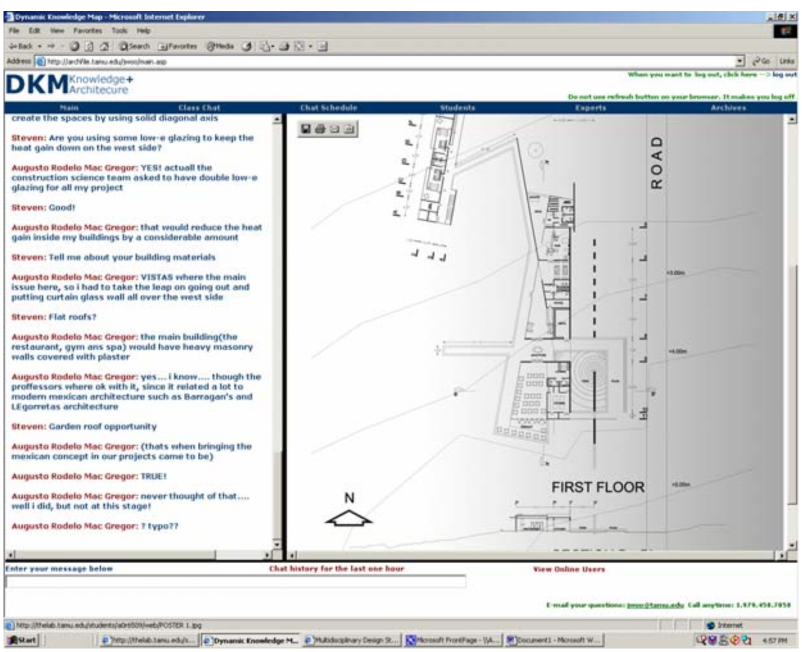


Figure 3.3 Screen shot of the software

The software architecture is a server/client system and is programmed using ASP (Active Server Pages). ASP is a server-side scripting language for creating dynamic Web pages that are able to retrieve and display database data and modify data records. An ASP script is executed through an embedded text script rather than a compiled program. The software runs on Windows 2000 Server and several types of PC workstations in the Texas A&M College of Architecture. The software is independent of any Web browsers, since it is a server-side application. MS Access is used for the system database.

3.6 Data Collection

Four data types were collected for this research: chat transcripts, questionnaires, log files, and design artifacts. Software was used as a data collection instrument in this study, and chat transcripts were saved as records in a database system. In addition to the dialogue contents, other data was recorded to designate time, authors, recipients and other miscellaneous data. Design artifacts were also collected as Web pages illusgrating students' design solutions.

Two questionnaires were distributed to participating students who are requested to choose one of several degrees of Likert scale with a series of questions. The students were asked to fill out and return questionnaires immediately upon completion. The first survey was conducted before the observational period and collected the descriptive data about students' academic attitude, previous design experience and tacit knowledge utilization. The first questionnaire was distributed on paper, and the answers were tabulated by hand.

The second survey was conducted after the observational period. This questionnaire was designed to get feedback about software usability, future ideas, and user satisfaction. The questionnaires were discussed and edited by the research committee members in order to avoid common flow in the contents and structural design of the questions. The second questionnaire was conducted online so that responses could be collected after the final presentation.

Miscellaneous numerical data was collected by the log files of the database system embedded in the software. These log files record virtually every action that every user performed in the software, including logging in and out; creating, joining, and leaving dialogues. The students were reminded of the existence of log files several times during the observational period.

While the students used the prototype software, data was collected in the broader context of a typical design studio. Students were expected to refine their designs based upon the critiques received in the chat sessions. After getting design critiques, the students conducted their project according to the normal procedures and requirements of the studio. At the end of the semester, the studio was concluded by collecting final design presentations from the students for further data analysis.

3.7 Data Analysis

Data was analyzed using qualitative and quantitative methods including content analysis, protocol analysis, frequency counts of dialogues, and simple statistics.

3.7.1 Content Analysis

Two types of data were used for the content analysis: online chat transcripts and students’ design artifacts. The content of online chat transcripts comprises chat messages between design critiques and groups of students. Since the chat sessions were held exclusively for the design studio, all messages are related to the design projects. The students’ design artifacts comprised drawings and presentations that were produced in the design studio.

3.7.2 Questionnaires and Simple Statistics

Two questionnaires were distributed to the participating students to collect quantitative data and supplement internal validity of observational data. To understand the characteristics of samples, pre-experiment questionnaire was conducted. The variables in the questionnaire are as follows: age, knowledge gathering attitude, previous design experiences, confidence in technological judgments, and knowledge of the participants’ computing skills. The questionnaire data were used to determine whether the samples are initially equivalent on the questions, even though the groups were not formed by random assignment. The relationships between variables were explored using simple statistics of the sample. To understand the students' opinions on the software, a post-experiment questionnaire was conducted.

CHAPTER IV

CASE STUDY 1: NASA VIRTUAL DESIGN STUDIO

The first case study was selected to validate research methods and collect data for preliminary data analysis. In spring 2003, the National Aeronautics and Space Administration (NASA) and 8 schools conducted a collaborative design studio to develop a crew restraint system for space flights. Online chat software was used as the primary communication channel. This studio provided an opportunity to conduct initial tests of the theory proposed in the preceding chapters. This study demonstrates the applicability and feasibility of tacit design knowledge sharing in a distributed design studio. The research method was limited to a qualitative approach based on observation and content analysis. NASA professionals served as knowledge holders while undergraduate students participated as knowledge seekers. All chat transcripts and students' design artifacts were collected. Interpretive content analysis was conducted to help develop theory of tacit knowledge sharing.

4.1 Settings

The design studio was conducted during the 2003 spring semester. A distributed design studio was initiated by NASA to develop requirements, guidelines, and conceptual designs for an ergonomically designed crew restraint system. The agency was interested in benefiting from the creativity and ingenuity of undergraduate students while providing students with a challenging subject for a class project. NASA final deliverables included:

- Development of functional requirements
- Design concept prototype development
- Evaluations of concepts through computer modeling
- Microgravity evaluation
- Implementation plan

Since no school has experience in crew restraint systems design, NASA staff members exclusively provided knowledge resources about crew restraint system design. At the beginning of the design studio, the agency provided a set of documentations containing extensive data, information, and knowledge about crew restraint systems in video, print, and photographic formats. The documents provide details of the requirements already developed, lessons learned, and information about existing restraint systems designs. This same documentation was previously used to develop preliminary operational and functional design requirements for a multi-purpose crew restraint system, and additional documentation was provided upon request. Students used the documents as a manual for proposed design concepts. The documents were posted and accessible through the password-protected web site called PostDoc (https://postdoc.arc.nasa.gov) as shown in Figure 4.1.

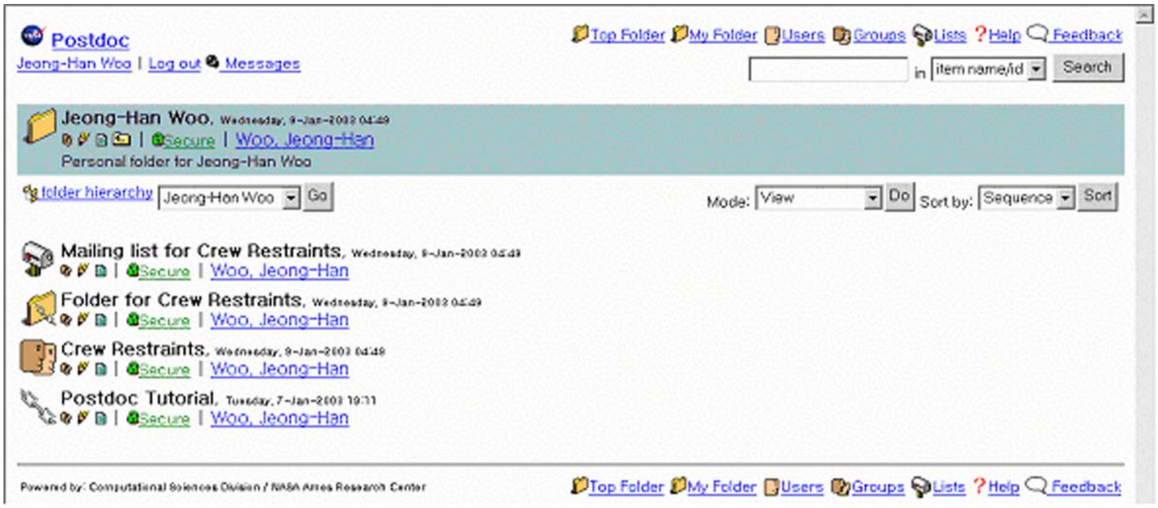


Figure 4.1 Screen shot of PostDoc main page

While all knowledge resources were posted on the PostDoc site, each school held physical face-to-face meetings with their course instructors. In addition to the accessible documentation, 3 NASA professionals shared their tacit knowledge by actively communicating with students using an online chat system (http://www.nsbri.org/Chat/hhfo/). The chat system used was typical chat software providing login awareness of the system users and supporting one-to-one communication. All dialogues were saved as natural conversations and made accessible for student review in order to share ideas and expertise in the dialogue.

Two chat sessions were conducted as open forums for questioning the experts. Throughout the two chat sessions, students held reflective conversations with NASA staff. The first chat session was conducted from 2:00 pm to 5:00 pm on February 5, 2003: 17 people from 5 different schools and 3 NASA engineers participated.

Participants generated 170 messages. The second chat session was conducted from 2:00 pm to 4:00 pm on February 6, 2003: 13 people from 4 different schools and NASA participated, and 107 messages were generated. All dialogue was captured and posted on PostDoc. Additional one-on-one chat sessions were conducted, but they did not add significance to the forum discussions.

4.2 Participants

The design studio was led by 4 NASA design professionals. Approximately 70 undergraduate students and 10 faculty members from 8 schools were invited to this design studio. All undergraduate students are naïve designers in terms of design experience, represented multiple design disciplines and approaches such as architecture, mechanical engineering, industrial engineering, and human engineering. Furthermore, none of the students had experience in design for zero-gravity space.

4.3 Data Analysis

The data used in analysis include knowledge resources provided by NASA, students' design artifacts and the chat session transcripts. Data for this study were downloaded from the PostDoc website hosted by NASA. NASA provided six different tacit knowledge resources via the Web site as shown in Table 4.1. The primary tacit knowledge resources are chat transcripts captured by NASA staff and posted on PostDoc. "Preliminary Focus Group Findings" refers to the summary of a series of meetings held to discuss lessons learned from "Restraints and Mobility Aids (R&MA)" and solicit ideas and concepts for restraints. The summary of comments from design professionals is another example of tacit knowledge.

Table 4.1 Tacit Knowledge Sources

File Name	Format	Description
Preliminary Focus Group Findings	MS Word	Preliminary Focus Groups Meetings were held and findings were summarized.
Chat sessions	MS Word	Compiled questions and answers.
LSG Question and Answer	MS Word	Life Science Glove box Question and Answers dealing with hardware details of configurations.
Compiled Crew Restraint Comments	MS Word	Database of Crew Debrief comments on individual restraints (pros/cons).
Restraint Summit Comments	MS Word	Restraint Summit Meeting Summary Notes were compiled with crew comments of restraint systems currently on ISS.
Question and Answer Session Feb 21	MS PowerPoint	Presentation covering all the questions posed by participating universities.

Explicit knowledge resources were also posted on PostDoc. The contents of explicit knowledge resources cover mostly the disciplines and guidelines of restraint systems design. Conversely, the contents of tacit knowledge resources supplement explicit knowledge and exclusively deliver knowledge based on expertise.

Ethnographic studies conducted by Schön (1983) and Cross (2000) are good precedents for the data analysis of this study. Their studies show that detailed observation of behavior during design sessions enables systematic descriptions of designers' improvement following experts' instruction. Likewise, the main task of data analysis is to qualitatively observe improvements in the students' design performance as “reflection-in-action” (Schön 1983) in a design studio setting. While thoroughly searching for students’ knowledge reflection, this research qualitatively describes improvements in student design performance.

The first step began with reading the online chat transcripts from the two online chat sessions. The chat transcripts for one-to-one conversations were not included in this study, since the majority of the contents were simple clarifications of the discussion. The content of online dialogue comprises messages between NASA professionals and groups of students and faculty. The dialogue occurred as students’ questioned NASA staff about problems, and presented ideas for the resolution of the problems. A reading of the transcripts led to unsystematic grouping of topics into categories as follows:

- Comfort/Injury problems
- Foot Restraints problems
- Body Restraints problems
- Handrail problems
- Maintenance problems

There were no restrictions about what might count as a problem category. Themes were simply summarized during repeated reading. Then, the students’ design artifacts were thoroughly investigated.

4.4 Description of the Sessions

The virtual design studio was initiated with a telephone conference for all school participants and NASA engineers at the beginning of the 2003 spring semester. NASA engineers and studio participants held numerous online chat sessions and telephone meetings throughout the entire semester. At the end of the semester, the studio concluded by collecting final design presentations from the students.

The chat sessions opened with a brief welcome from NASA staff. Students then asked questions about crew restraints system. Messages varied in length. Since the chat sessions were held exclusively for the design project, all messages are related to the design of crew restraint systems. Some messages contained relatively long explanations about the situations on the international space shuttle. Since only three NASA professionals answered all questions from the students, the answers were frequently delayed.

After sharing extensive knowledge, the students developed their conceptual designs for a preliminary design critique. The design instructors and NASA engineers conducted a critique of the preliminary designs via a video conference for the design critique. In the next stage, students refined their designs. Students received consultations from NASA staff via chat sessions and their own instructors in the local design studio. The remainder of the design studio was primarily conducted with the instructors.

NASA reviewed the final projects internally with their own staff and ranked each project within each university, evaluating whether or not each project met the necessary requirements and showed enough feasibility to warrant pursuit as an actual design project. After posting the final design project on the Web site, the design studio was completed.

4.5 Findings

The findings of this study indicate that the online chat system is useful in sharing tacit knowledge for the early part of design processes in a distributed design environment. Experts' tacit knowledge appears to not only influence how students understand problems, but how they initiate conceptual design. This study provides empirical evidence regarding tacit knowledge sharing, and strengthens Schön's (1983) claim about knowledge reflection in design studio. Results from the qualitative investigation provided enough warrants for continuing with the main investigation.

4.5.1 Tacit Knowledge Sharing

Three NASA engineers actively participated in the online chat sessions. The role of NASA staff in the sessions was that of the knowledge holders. Because of their prestige, students eagerly interacted with them and attended closely to their comments. Furthermore, this process helped students comprehend the significance of tacit knowledge sharing, in addition to understanding how dialogues during the early stages of design can assist NASA staff and the students themselves. There were several dialogues such as:

<Student 1> Are these chat sessions set up for the various schools to share ideas as well?

<NASA 1> Certainly, you can use these sessions to share ideas as well.

<Student 2> Will the chat session be held routinely?

<NASA 2> In regards to CHAT session times, we will try to hold them routinely if necessary. But for this week it will only be today (now until 5 pm Central) and tomorrow 2 - 4 central time.

The participants definitely wanted to talk with other team members via chat sessions to share ideas and experiences. Particularly in a complex and unusual project like this, the importance of tacit knowledge sharing is amplified. Increasingly, the students expected to face situations in which the knowledge they hold is no longer sufficient to complete a good design project, since the knowledge needs in this studio are dynamic and complicated. Therefore, experts' tacit knowledge should be shared to achieve better quality on design projects.

<Student 3> Any chance of getting complete transcripts of both chat sessions, say, on post-doc?

< NASA 1> Yes, we will be sending out the complete transcripts of both chat sessions.

< Student 4> The summary of chat session yesterday organized by topic was really useful. Thanks.

< Student 3> Thank you so much, Rosie and Mihriban! Super-helpful chat.

< NASA 1> I believe there is another Chat at 4 pm Central. I think this is our cue.

This series of dialogue indicates the successful conversion of tacit knowledge to explicit knowledge. In this dialogue, the participants affirm that they shared significant tacit knowledge about the project. NASA professionals offered numerous professional recommendations, intuitive expectations, and their experiences on other crew restraint design projects. The students knew that they could not receive such advice from explicit knowledge sources currently in existence. Because of past experiences, NASA professionals can share what must be undertaken at many given point. However, conventional tacit knowledge sharing requires physical face-to-face interaction (Nonaka and Takeuchi 1995). In a distributed design studio, there is a need to share tacit knowledge at remote locations, such as different buildings or different offices, and receive immediate help. The online discussions addressed the same topics that could be discussed in the meeting room. It is less dynamic than face-to-face meetings, yet more dynamic than just written messages alone.

4.5.2 Analysis of Design Problem

The findings of this study show that experts' tacit knowledge is more informative than explicit knowledge during analysis of problem. At the first stage of the design studio, all students thoroughly studied the provided documentation. The documents broadly covered all aspects of crew restraints design such as design guidelines, manuals, technical specifications, and graphic samples. However, those materials are limited in use for the analysis of problem. Therefore, through the chat sessions, the students asked about problems they encountered. Cross (2000) says "the very first conceptualizations and representations of problem and solution are critical to the kinds of searches and other procedures that will follow, and so to the final solution that will be designed." A significant portion of the online chats was devoted to the clarification or explanation of real problems, and the majority of problems were identified in chat sessions. The discussions focused on important questions such as:

- Have there been muscle injuries due to existing restraint systems?
- Have the foot loops been useful in any particular task?
- Do the LSG arm holes restrain the upper body?
- Do they want their feet restrained completely or would they prefer more flexibility?

The answers from NASA for these questions formed the most concrete evidence of the problem and were a part of the problem statement of each design project. Students quickly identified particular problems that would influence their approach to developing a conceptual design. Many problems were also clarified through the online chat sessions. The students could easily comprehend a well-defined problem, and then focus their work on one of those problems.

During online chat dialogues, one student opened up a new question about current discomfort caused from current restraints. The following dialogue examples demonstrate typical conversations influencing the design. NASA staff was also able to provide information from previous experience.

<Student 5>	Have there been muscle injuries due to existing restraint systems?
<NASA 1>	We didn't have any serious muscle issues but some discomfort reported. Use of handrails as a foot restraint caused some discomfort on the toe knuckles.

The first problem the students encountered was the use of handrails as a foot restraint. Based on this problem, some of the students offered proposals to handle this problem as shown at Figure 4.2.

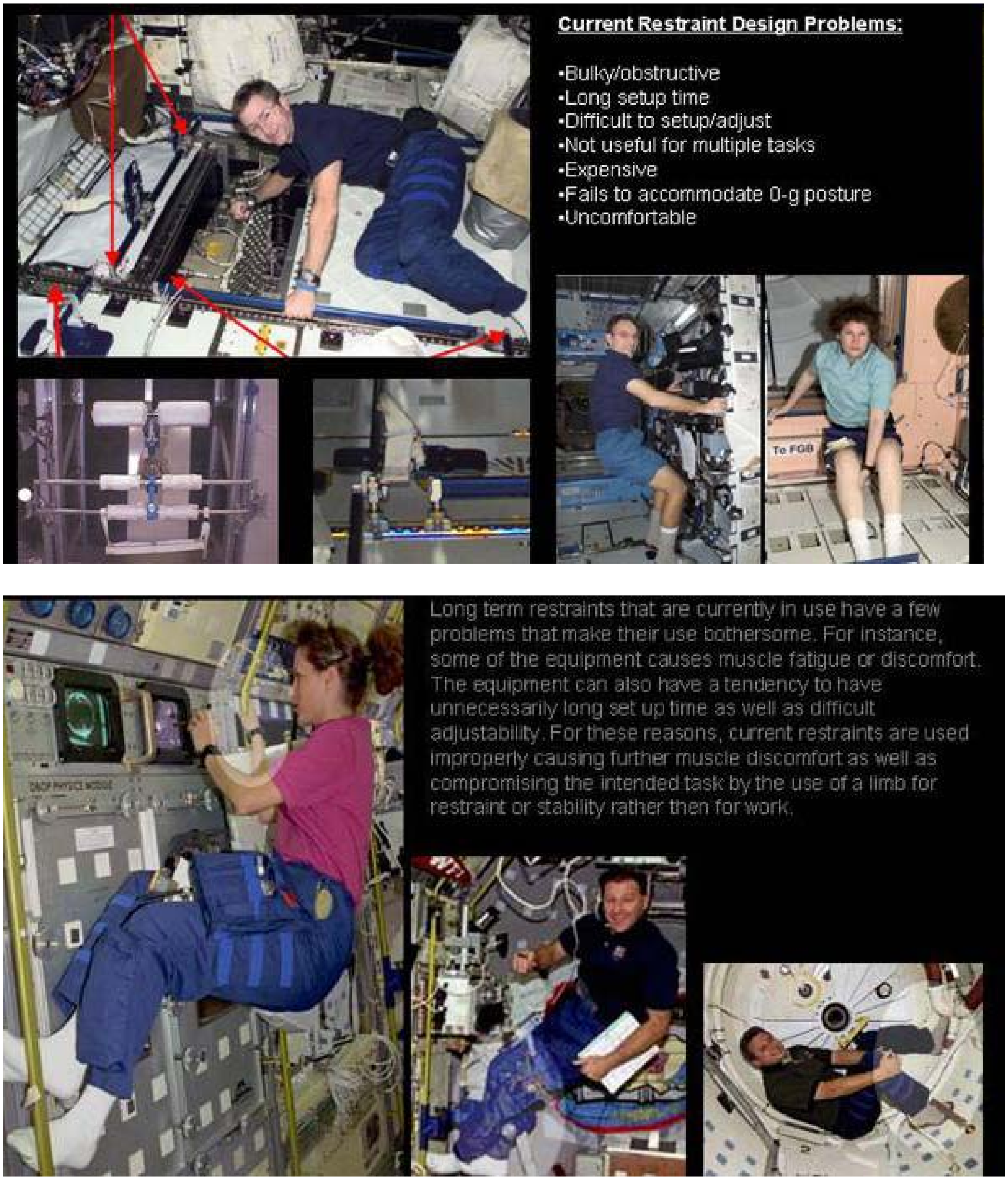


Figure 4.2 Design example 1

The second problem students encountered was complaints about the foot loops.

<Student 6> There have been numerous complaints about the foot loops. Have the foot loops been useful in any particular task?

<NASA 1> Foot Loops - 1. Adjustment mechanism is not effective and comes loose 2. Collapsible so not easy to get in 3. Footplate is slippery with socks so they curl toes to restrain

<Student 7> Can any spring loaded mechanisms be utilized in the restraint designs?

<NASA 1> As long as it is simple, spring loaded mechanisms can be utilized.

Based on above dialogue, a student generated the following design proposal (Figure 4.3).

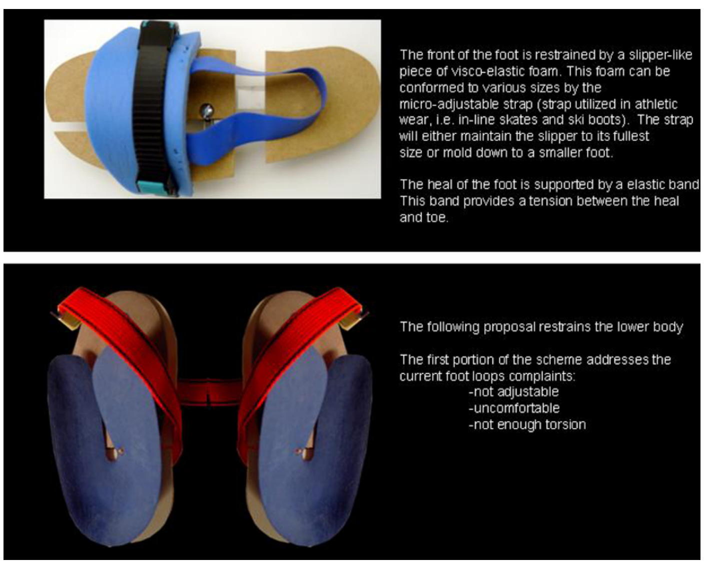


Figure 4.3 Design example 2

The third problem was the storage and maintenance of the restraint systems.

<Student 8>	How much space is devoted to storing restraints on-board the ISS?
<NASA>	Long term & temporary stowage config for restraint are critical. There isn't any set dimensions. However, for temp. stowage, the config should be out of the aisle as much as possible with minimal interference with its surroundings. Also, it should be easily temp stowed. We can provide dimensions for the stowage containers.

<Student 9>	Are current RMAs considered adequate for multiple rack translation & maintenance, including the tilt-out procedure?
<NASA>	In regards to your question of current RMAs for multiple rack translation and maintenance.....
<NASA>	Crew can do the work but is not sufficient for safety and not ideal. Current RMAs do not completely assist adequately for all tasks.
<NASA>	did I answer your question?

The fourth problem is long set up time and difficult adjustability. A student writes a problem statement as follows (Figure 4.4):

> Long term restraints that are currently in use have a few problems that make their use bothersome. For instance, some of the equipment causes muscle fatigue or discomfort. The equipment can also have a tendency to have unnecessarily long set up time as well as difficult adjustability. For these reasons, current restraints are used improperly causing further muscle discomfort as well as compromising the intended task by the use of a limb for restraint or stability rather then for work.

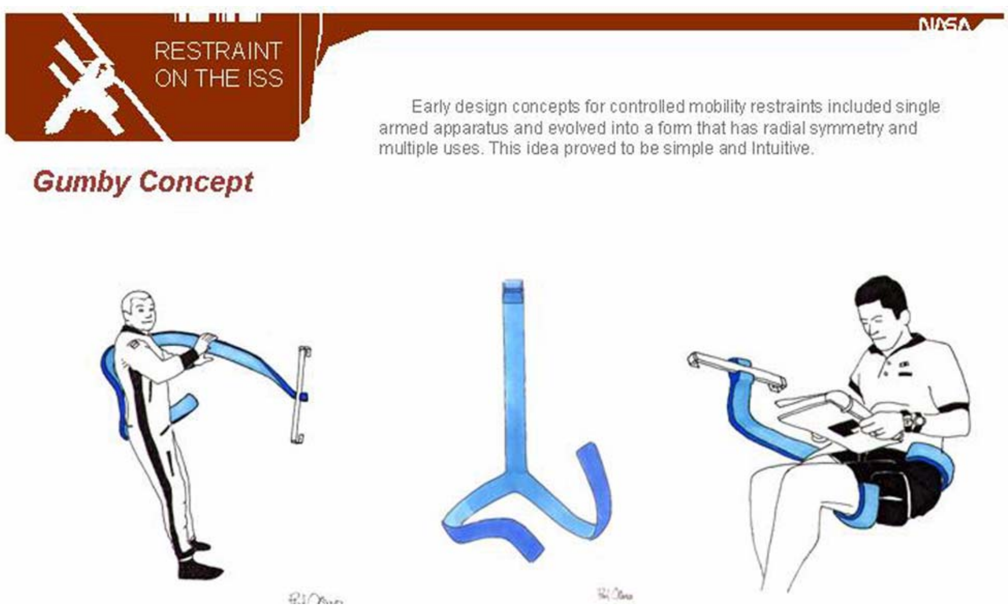


Figure 4.4 Design example 3

In the dialogue, NASA staff said that the handrails are the most effective system onboard ISS. A NASA staff member said:

> To add on to it, the only one that has been reported to be the most effective one onboard ISS thus far is the handrails. Quick note that there are plenty of them onboard thus they don't need to move or remove it.

So, many students tried to design a variation of the current handrails as shown in Figure 4.5.

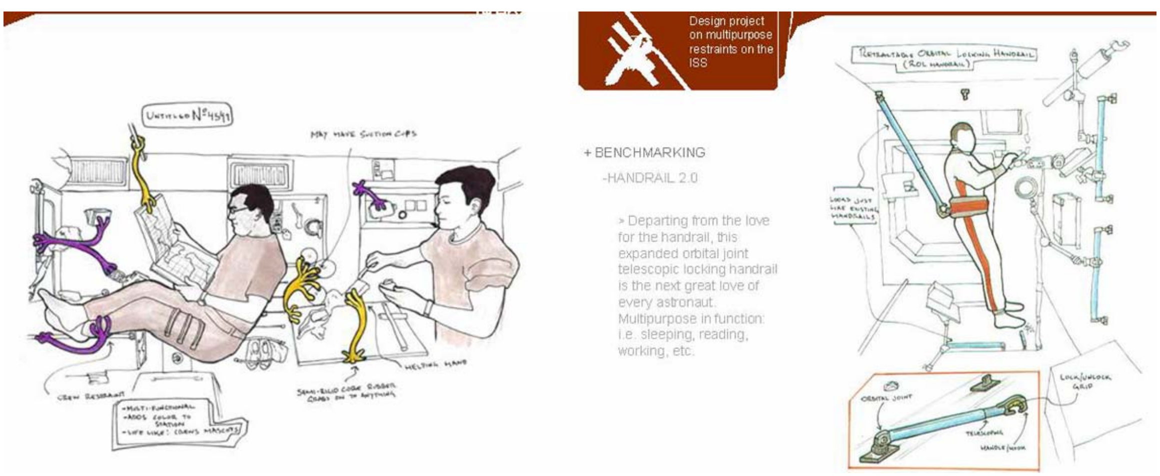


Figure 4.5 Design example 4

Above design samples are from the architectural design schools. Students from the engineering schools used a different design approach. Schön (1983) also insists that generic design processes can be significantly differentiated by the bodies of knowledge specific to various professions. Students from mechanical engineering generally possess such a differentiated design approaches. For example, they are interested in design data such as anthropometrics, dimensions, materials and environmental data, rather than the problem awareness itself. Here are some examples of their dialogues:

<Student 10>	What are the size/weight constraints and envelope dimensions of the crew restraint?
<NASA>	there isn't any specified in any documentation. But, due to the upmess, both size and weight should be minimized as much as possible.
< Student 11>	is there an IVA specific document for design requirements, as in NASA STD-3000?
< NASA>	yes, SSP 50005 is for the vehicle human factors requirements and SSP 57000 is for the payloads human factors requirements. We can try to have them available on postDoc (at least the relevant sections),

The scientific approaches from engineering backgrounds appear to be too realistic to develop a creative and innovative design. So, NASA staff suggested that students ignore engineering data and concentrate on issues of stability, comfort, ease of use, and ease of installation.

<Student 14> Are the handrail and seat track a vendor item? Can we obtain samples or detailed engineering drawings of these parts? Is seat track still to spec MS33601?

<NASA> Jason--yes, the seat track that we use is made primarily by Boeing (although some international partners get seat track elsewhere). I do not know of a capability to get a sample.

<NASA> I'm not familiar with MS33601....is this a military spec? For the purpose of this project, we are looking for CONCEPTUAL designs, so the details of the seat track are not particularly critical

<Student 14> Thanks Susan

<Student 15> I know there is a Generic Design Requirements Document (GDRD) for EVA, is there one for IVA?

<NASA> I believe there is a requirement document for IVA equipment design, but for the purpose of this project it is not necessary for CONCEPTUAL designs. Does this answer your question?

<Student 15> Yes, thank you

4.5.3 Works from Non-Participant School

Only one school did not participate in the online chat sessions. Its students’ approaches to recognizing problems, formulating concepts, and developing designs are markedly different from those of the other schools. The students from the non-participant school initiated their project by performing an extensive literature search and review. While the literature provides an impressive amount of information, there are limitations for understanding real problems for the crew restraints system. Design artifacts reflecting tacit knowledge are more likely to be complete, and thus more credible.

4.5.4 Knowledge Archives

The chat scripts are especially useful when they remind the participants of the topics discussed. Because of the volume of material discussed, students might have difficulty in recalling all the conversations. If students have access to repositories containing such conversations, their work reflect experts' knowledge to a greater extent, and it is more fruitful and competitive. To this end, a method for capturing knowledge should be developed. When professionals handle information of high value, they intuitively want to capture it, but they cannot spend time to capture and store in an appropriate place. When professionals leave an organization, knowledge also leaves. Therefore, systems should extract, reflect and retain experts' tacit knowledge within organizational boundaries before they leave. Processes to develop these systems in a working organization are heavily dependent upon the manager's business strategy. What is required is a manager who can imagine a more desirable future and invent ways of reaching it.

4.5.5 Concluding Remarks

This study conducted a content analysis on three different types of media: tacit knowledge resources, explicit knowledge resources and students' design artifacts. It is difficult to separate the impact of tacit knowledge only and to determine which type of knowledge is more effective, since students typically develop projects based on both types of knowledge. However, online chat dialogues contain exclusive tacit knowledge provided by NASA. Since NASA staff holds exclusive tacit knowledge of crew restraint systems, the answers or comments about the design work contained critical suggestions. The findings of this study show that students' design artifacts are practically improved by tacit knowledge sharing. Expert designers therefore appear to be a richer source of new ideas and alternative perspectives.

The online chat system seemed to be useful in sharing tacit knowledge for the early part of design processes in a distributed design environment. It is apparent that tacit knowledge sharing generates a well-defined problem. The participants share their knowledge and reflect the solutions in action. Experts' tacit knowledge appears to not only influence how students understand problems, but how they start conceptual design. We believe this study provides empirical evidence regarding tacit knowledge sharing, and strengthens Schön's (1983) claim about knowledge reflection in design studio.

Until now, many design studies have been conducted concerning collaborative media in the architectural profession. However, these studies rarely focus on the impact of tacit knowledge on the design artifact. This unexplored topic of the design studio enabled us to clearly observe the effect of knowledge reflections on the students' design artifacts. This study qualitatively observed the improvements of students' design performance in a design studio setting based upon two aspects: knowledge reflection and design improvement. The qualitative content analysis was conducted on all dialogue records, documentations provided by NASA and students' design artifacts. This study is significant, because the findings guide the development of an appropriate knowledge management strategy for architectural practitioners.

Furthermore, the significance of this study introduces architectural practitioners to the practical necessity of tacit knowledge sharing. They must develop more effective ways to share employee's various levels of tacit knowledge. While deeply ingrained tacit knowledge may only be shared by learning by doing (Schön 1983), lower levels of tacit knowledge can be effectively articulated and shared by using Internet technology.
The essence of tacit knowledge sharing is a collaborative attitude and a willingness to collectively accomplish work and to jointly discover and develop the best solutions. This study suggests that a distributed design studio should be implemented based on the collaborative culture. A distributed design studio should consider cultural factors influencing knowledge sharing, trust and collaboration. Improving collaboration and cultural trust is one of the major tasks for effective knowledge management. This study was limited to qualitative research methods. To quantitatively analyze the impact of tacit

knowledge on design artifacts, a questionnaire could be distributed to the participating students in the future.

CHAPTER V

CASE STUDY 2: PECKERWOOD GARDEN DESIGN STUDIO

The results from the NASA case study provide enough warrants for continuation of the study with a further investigation. A second case study was conducted in a graduate-level multidisciplinary design studio at Texas A&M University, College Station, TX, during spring 2004 semester. The research design and procedure were identical to that used in the NASA case study, except that two questionnaires were distributed for the research. In addition, different software was tested to learn about how the software affects the exchange of tacit knowledge. The implementation of the software allowed students to seek tacit knowledge to apply to their design projects by communicating across the Internet with design critics. The chat transcripts recorded by the software were used in conjunction with demographic data and interviews to draw conclusions about software use in support of tacit knowledge exchange during a design project.

5.1 Design Problem and Setting

The design studio was organized by three faculty members as a collaborative project involving each of the three departments in the College of Architecture: Department of Architecture, Department of Landscape Architecture and Urban Planning, and Department of Construction Science. Graduate students from the Master of Architecture, the Master of Landscape Architecture, and the Master of Science in Construction Management were enrolled in the course. The three instructors met with the students during the regular studio time, which was twice a week for 4 hours per session, 3 days a week throughout a 15 week semester.

The design studio undertook a project for the long- term planning and design of facilities at the Peckerwood Garden in Hempstead, Texas. The 20-acre garden, established in 1971, is an outstanding repository of rare and unusual plants and unique folk art from Mexico and the southern United States. The students were required to develop a master plan and building designs while considering a ecological system which incorporates the garden's wetland areas.

The prototype software was introduced and employed by the students as a complement to traditional face-to-face design critiques. The software was installed on a college server and was available as an Internet-based service. The computers used for the chat sessions were located in a college computer lab and are typical, commodity personal computers connected to the Internet. The lab was very convenient to use and was carefully secured so that students could not change computer configurations or network settings. Most students used Microsoft Internet Explorer to access the pages of the application, but other web browsers could be used.

Numerous online design critiques using the software were conducted. In many instances, the online sessions involved practitioners or consulting professors who participated from remote locations.

5.2 Participants

The participants included students, who may be thought of as “knowledge seekers”, and design critics, who may be thought of as “knowledge providers”. Twelve graduate students participated in the training and pre-test questionnaire. Of these initial participants, seven students participated in real-time chat sessions and completed the post-test questionnaire. Participation in the research was voluntary and had no bearing on course grades.

A total of twelve design critics logged into the system for various chat sessions. Seven separate chat sessions were conducted during a one month experimental period. Each chat session lasted about one hour. The students produced 597 messages (Table 5.1) while the design critiques produced 201 messages.

Table 5.1 Software usage

Students	Login Frequency	Total time	No. of messages
Student 5	4	3:11:04	54
Student 3	16	2:56:06	150
Student 6	4	2:52:24	75
Student 4	10	2:36:42	73
Student 1	4	2:34:00	43
Student 7	14	2:04:28	136
Student 2	2	1:31:42	66
Student 8	6	0:08:41	0
Student 9	2	0:00:54	0
Student 10	2	0:00:06	0
Student 11	0	0:00:00	0
Student 12	0	0:00:00	0

The participants were carefully trained before the sessions began. The training session started with distributing a software tutorial which the students were asked to read. Then, a twenty-minute presentation was conducted by the author followed by a question and answer session.

Prior to the training session, a questionnaire was distributed to gather participant background and demographic information. The students' average age was 25 years with one or two years of work experience, and they all had previous experience on a similar project type. Table 5.2 shows the pre-test questionnaire results indicating the demographic and educational background of the students as well as their work experiences.

The design critics are leading faculty members, practicing architects, and industry experts. They participated using the Internet from remote locations, including other parts of the campus, Dallas, TX, Houston, TX, Washington, DC, Mexico, Guatemala, and Chile (Table 5.3). The design critics were recruited to enable students to gain tacit design knowledge at a higher level in a practical situation. The critic's expertise included sustainable design, space manipulation, landscape design, and interior design.

Table 5.2 Student characteristics

Category	Average	Max.	Min.
Age (Years)	25	29	22
Work Experience (Months)	16	30	0
Design Studio Experience (Frequencies)	11	20	6

Table 5.3 Design critics characteristics

	Location	Profession
Design Critic 1	Guatemala	Professor
Design Critic 2	Dallas, TX	Architect
Design Critic 3	College Station, TX	Landscape Architect
Design Critic 4	College Station, TX	Professor
Design Critic 5	College Station, TX	Design builder
Design Critic 6	Chile	Professor
Design Critic 7	College Station, TX	Professor
Design Critic 8	College Station, TX	Professor
Design Critic 9	Washington, DC	Professor
Design Critic 10	Houston, TX	Architect
Design Critic 11	Houston, TX	Architect
Design Critic 12	Mexico	Professor

5.3 Data Collection and Analysis Methods

Two data sources were used for content analysis: online chat transcripts and students' design artifacts. Content analysis of the chat transcripts and the design artifacts provides qualitative evidence for the effectiveness of the software for sharing tacit design knowledge. The online chat transcripts comprise messages between design reviewers and groups of students. The students' design artifacts comprise drawings and presentations that are produced in the design studio. Progress drawings and sketches were collected in addition to final presentations. Students' design artifacts were examined to discover how the students applied the shared knowledge and made some improvement as a result of the online chat conversations.

Analysis of the chat transcripts consisted of an iterative search for design knowledge that was meaningful for the design projects. The students' design artifacts were comprised of drawings and posters produced in the design studio and were examined to discover any improvement resulting from the online chat conversations.

Quantitative data mainly supplemented qualitative observational data to triangulate evidence. Two questionnaires were distributed to the participating students to collect quantitative data. The initial questionnaire was made available on the first day of the experiment and collected descriptive data about students' attitude toward gathering design knowledge, previous design experience, tacit knowledge utilization, computer skills and the use of CMC. The questionnaire data was used to determine whether the student characteristics were initially equivalent on the questions, even though the participating students were not formed by random assignment. The online student questionnaires consisted of 4-point Likert type and semantic differential scale check boxes. The submission of all questionnaires was completely voluntary and was not required by the instructors or the researchers.

The second survey was distributed on the last day of the design studio. It was a post-test questionnaire that is primarily designed to obtain feedback about software usability, ideas and satisfaction. The relationships between variables in the sample were analyzed using simple statistics.

Numerical data about actual usage of the software was collected automatically by the software using log files. These log files effectively recorded every action that every user performed within the software, including logging in and out; creating, joining, and leaving dialogs; and reading chat archives.

5.4 Procedure

During the 10th week of the semester, the instructor announced that the software would be used as a virtual design review tool. The students received a presentation to explain the software functionality and a group training session was presented by the researcher. The first questionnaire was distributed in paper format, and answers were tabulated by hand and coded by participants. Design artifacts were collected twice – once before and once after the series of chat sessions. The design artifacts (primarily drawings) were all in digital format so that the artifacts could be uploaded onto the Web server for the design critiques to use during the chat sessions. Drawings included site plans, floor plans, sections, elevations and 3D perspectives.

5.5 Findings

5.5.1 Findings from Content Analysis

This chapter introduces five cases of the online chat to explain how the students applied shared tacit design knowledge to their design projects. The analysis of chat transcripts and design artifacts is described in this chapter in order to answer the second research question, “Does the software assist in capturing and sharing experts’ tacit knowledge?” and the third research question, “Do students who share tacit knowledge through online conversations apply the knowledge to their design artifacts?”

The findings reveal that the chat sessions help in sharing professional suggestions, identifying real problems, and providing technical help. However, the chat sessions were not going well when the chat schedule is too tight because the design critics did not have enough time to understand the projects and be prepared to provide design critiques. Some cases also reveal that the most effective ways of organizing chat sessions to share tacit knowledge is matching good expertise on the projects. Otherwise, tacit knowledge that is shared during the chat session could be wasted and ignored.

Student 1: Professional Suggestions

Student 1 is a 24 year-old male student with 9 months practical experience as an architectural intern in an architectural firm in the U.S. The questionnaire data indicates that he had the lowest usage of CMC technologies as compared to the other students because he had never used CMC technologies such as chat, instant messaging, or groupware for design projects at all. On the other hand, his data revealed the highest knowledge gathering attitude compared to the other students. He was also very interested in receiving critiques about his design concepts from practitioners in the industry.

A critic suggested adding more skylights and enhancing the visual quality of the space. Student 1 fully agreed with the suggestion and replied, “That is an interesting option which I had thought about earlier.” He was also able to revise his 3D images quickly as shown in Figure 5.1. This revision indicates a clear illustration of transferring the reviewer’s ‘generalized tacit knowledge’ into ‘specialized explicit knowledge’.

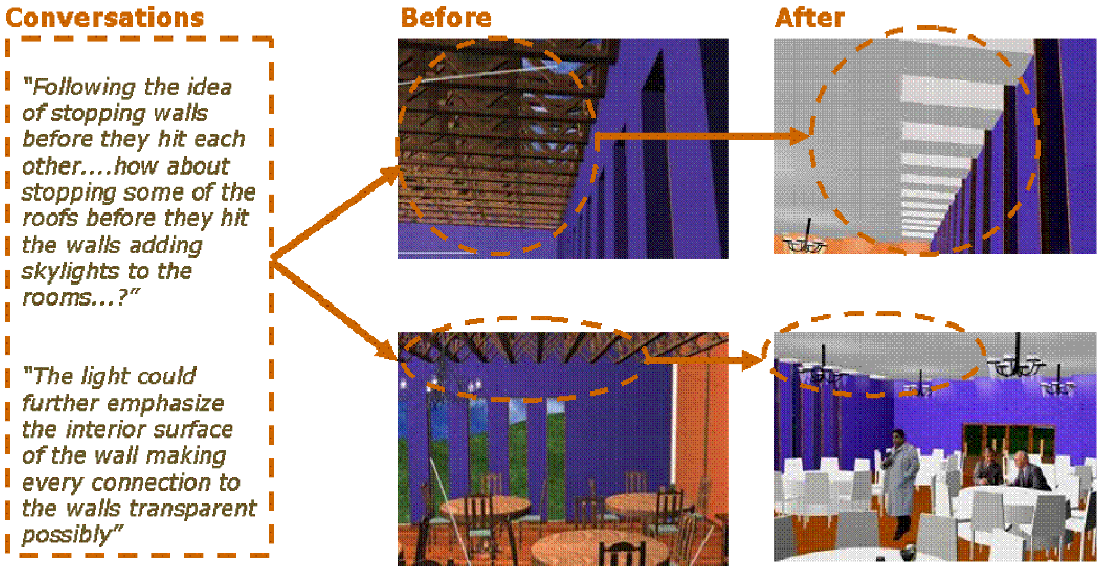


Figure 5.1 Student 1 example

<u>Student 2: Identification of Real Problems</u>

Student 2 is a 23 year-old female student with two years of previous practical experience in India. She has never used tacit design knowledge resources for her design projects, nor has she ever used chat, instant messaging, or groupware at all. According to the pre-experiment questionnaire data, she prefers to use asynchronized CMC technologies, such as email and discussion boards. Since she holds a higher tacit knowledge gathering attitude, she volunteered to participate in the first chat session.

Quite early in the chat session, the reviewers framed two problems. The problems were the narrow spacing between the buildings and the landscape design for the central garden area. One reviewer suggested creating a wider spacing between the buildings. Another reviewer suggested celebrating the central landscaping area, thereby transforming it into a more meaningful space (Figure 5.2).

The critics' comments formed the most concrete evidence of the problem. Quickly, Student 2 was able to frame particular problems that would influence her approach to developing a final design. Finally, Student 2 produced a revised floor plan which incorporated the comments from the reviewers, as shown in Figure 5.2.

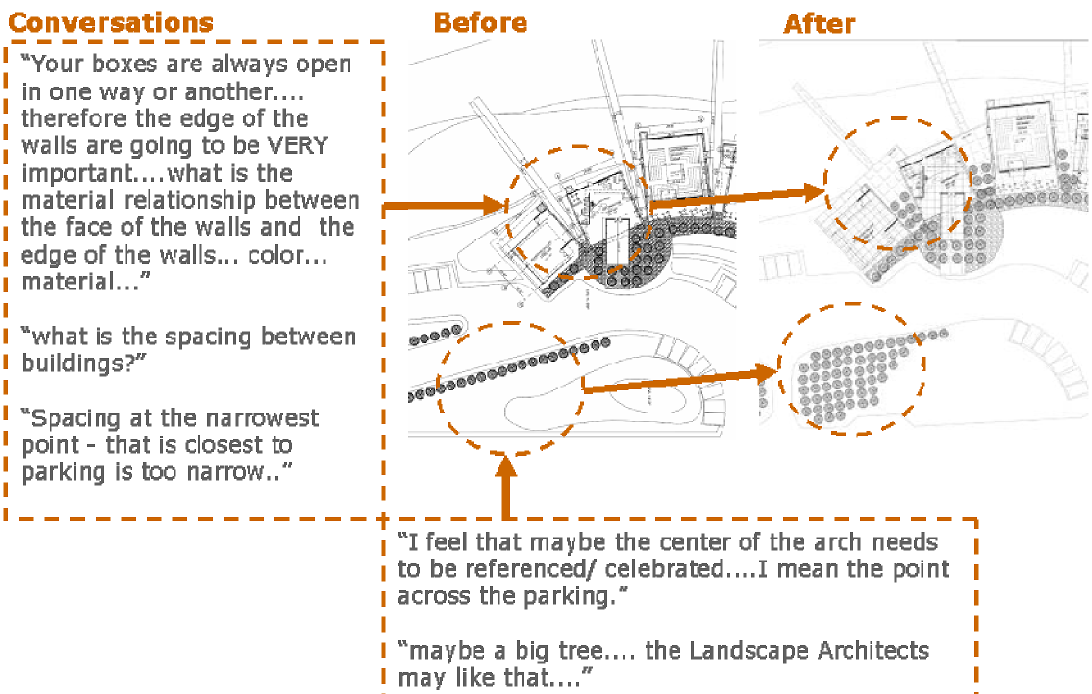


Figure 5.2 Student 2 example

Eventually, she decided to integrate one reviewer's comments and changed the drawings. After the chat sessions, her perception of the chat session's usefulness significantly increased from "Not at all" to "Somewhat." Her overall evaluation of the software was the highest level—"Very Enjoyable."

Student 3: Technical Help

The following case shows how easily the students receive technical help through the chat sessions. One design critic representing the local chapter of USGBC (United States of Green Building Council) was particularly knowledgeable about sustainable design. He suggested composite (wood and recycled plastic) decking rather than hardwood decking to incorporate the concepts of sustainable architecture. Student 3 was able to ask a few questions about the composite decking option and agreed to use it (Figure 5.3).

Conversations

Reviewer: The decking is an opportunity for the composites - wood and recycled plastic.

Reviewer : Trex, Choice-Dek, etc.

Student 3: do they have the same visual quality as hard wood?

Reviewer : Exterior wood is a maintenance nightmare

Reviewer : The composite decking looks very different

Student 3: that is one thing i want to avoid… maintanance costs

Reviewer : If you go with wood, consider fastening the deck boards from below. There are various methods these days. I know this is very detail oriented, and you are trying to design the whole building.

Student 3: probably i will change from hard wood to composite.

Before **After**

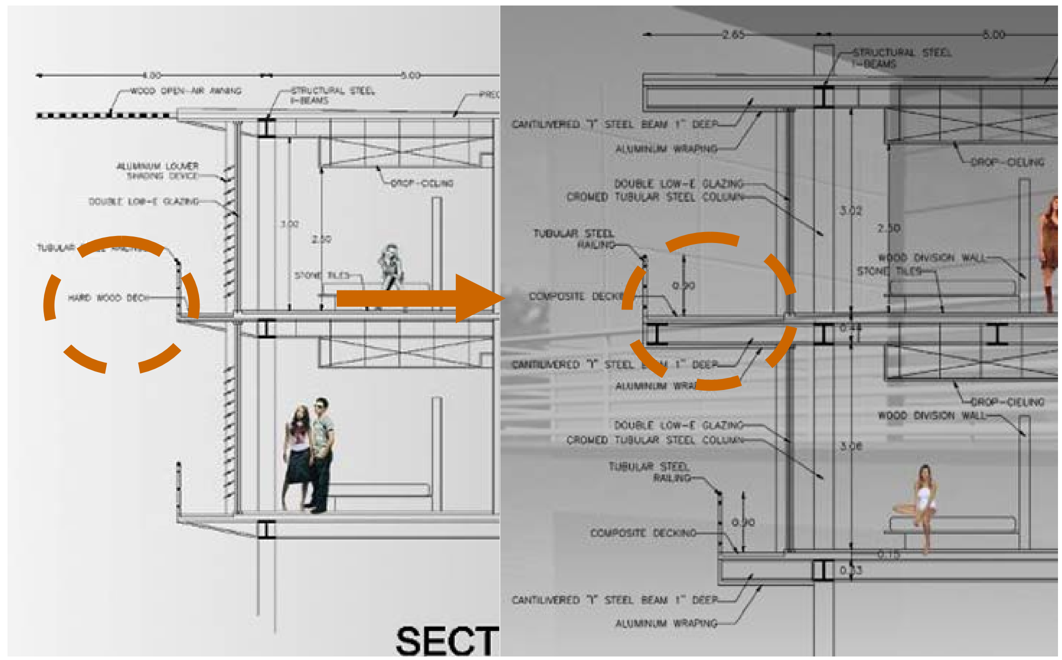


Figure 5.3 Student 3 example

Student 4: Short Timeframe

The following case shows the importance of the timing of the conversation. The chat session was scheduled at the later stage of the design project due to the complexity of scheduling. As shown in Figure 5.4, a design critic and Student 4 discussed the shape and scale of the massing elements. A design critic pointed out that Student 4 should consider the viewer-perceived scale. The comment was very useful for Student 4 and he agreed to make some changes according to the comment. However, student 4 did not have enough time to incorporate the suggestion. Timing is a delicate issue for tacit knowledge sharing, simply because there is lower chance to apply knowledge if the timing is not right. Sufficient time should be set aside to allow for thorough discussion of the project.

Student 5: Mismatched Expertise

The following case shows the importance of just-in-time expertise matching. The critic is a director of a local chapter of USGBC (United States of Green Building Council), who has very extensive knowledge in sustainable architecture design. Student 3 is a person with design philosophy from modern architecture and high-level graphical presentation skills. He is also very positive about adopting technology and has plenty of experience using CMC technologies. However, his knowledge gathering attitude indicated 2.2, according to the 4-point Likert scale (Figure 5.5).

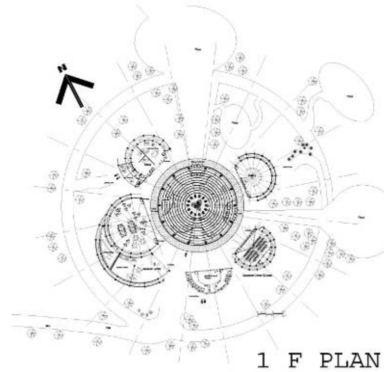
Conversations

Reviewer: Could you explain to me why did you choose the circular form and how are you going to relate your project with the rest of the proposals of your team?

Student: i wanted to remind people the shape of flower. Other team members also use the similar shape, circular form and tectonic structure.

Reviewer: Be careful with the questions related to the form. You should not forget that the flower concept should be understood from the human scale, not from the helicopter. On the other hand, the important thing is the essence or the spirit of a concept not only the form. So it might be possible also to interpret the flower concept with other forms. On the other hand, I recommend you to connect the outer space with the interior of your green house, visually or functionally. Try to create a more continuous space.

Before



After

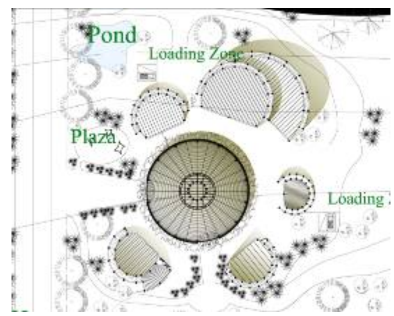


Figure 5.4 Student 4 example

In the chat session, Student 3 and the reviewer began the discussion from different perspectives and philosophical standpoints. Even though Student 3 did not seek advice from "green architecture" perspectives, the reviewer suggested an alternative decking option made of composites, woods, and recycled plastics. The suggestions about the materials were not attractive to the student. Although the reviewer has vast knowledge about sustainability, the student did not recognize the significance of sustainability for the project.

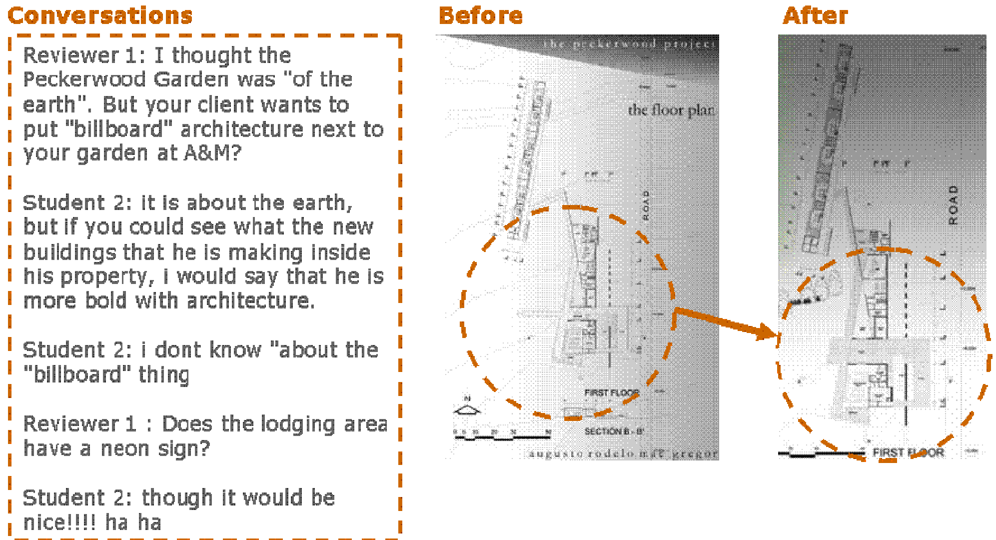


Figure 5.5 Student 5 example

Although they spent a lot of time discussing sustainability, Student 3 did not incorporate the comments into his project. Content analysis of this chat session suggests that just-in-time expertise matching, and a higher sense of cohesion might be a very strong enabling factors for sharing tacit design knowledge in a distributed design environment. In the words of Student 3:

> Experts need access to the history of the project such as who is the client, what are the goals, what skills or knowledge do the various students (or agents) bring to the project.

5.5.2 Findings from Quantitative Data

The analysis of the questionnaires and the log files is described in order to answer the following question, “How does the software assist in capturing and sharing tacit design knowledge?” Figure 5.6 illustrates that the students primarily use explicit knowledge sources such as the internet, manuals and books when they need help on technical issues. Tacit knowledge resources, such as industry professionals, professors, and senior students, are not favored knowledge resources, even though they could provide very valuable knowledge. Instructors are definitely the most trusted resource since instructors assign grades. Figure 5.7 shows the relation between the use of tacit knowledge resource and knowledge gathering attitude.

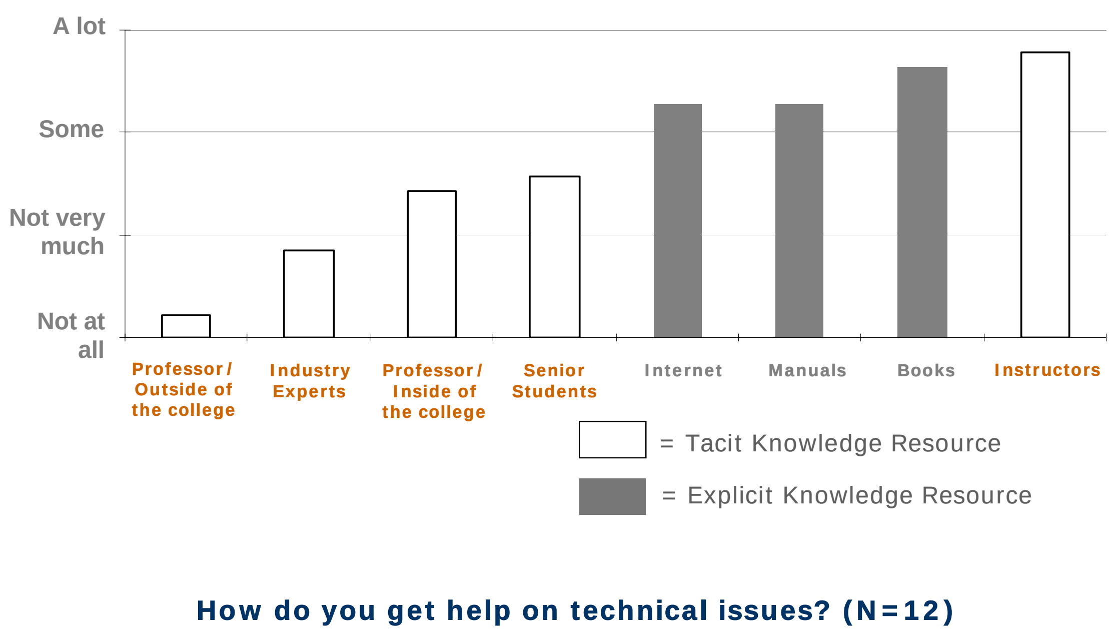


Figure 5.6 Technical resources

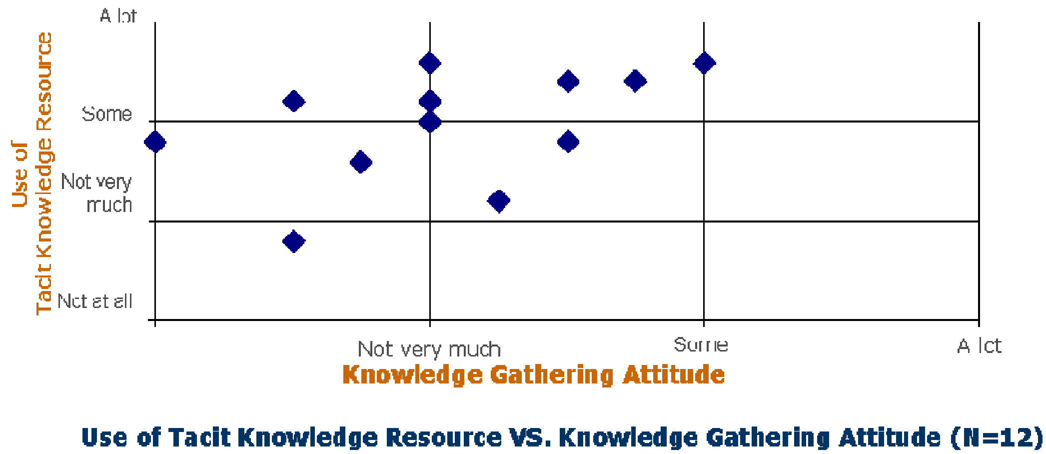


Figure 5.7 Use of tacit knowledge resource vs. knowledge gathering attitude

According to the questionnaires, most participants reported that their experience with the software was very enjoyable and the software is well-designed to support sharing of design knowledge. Participants indicate clear expectations that synchronous chat could be integrated with visual display, such as "mark-up systems."

The students varied their perceptions of the integration of CMC technologies in design studios. The questions about CMC technology perceptions were asked twice in both questionnaires. Figure 5.8 shows the difference in the perception of CMC technology before and after the experiment. The perception of phone, groupware, virtual directory, and email stay constant. However, their perception about chat/instant messaging and video conferencing was greatly improved. The results further suggest that students recognize chat/instant messaging as an opportunity to share tacit design knowledge and interact with others, and that they do not see it just as a communication medium capable of faster communication.

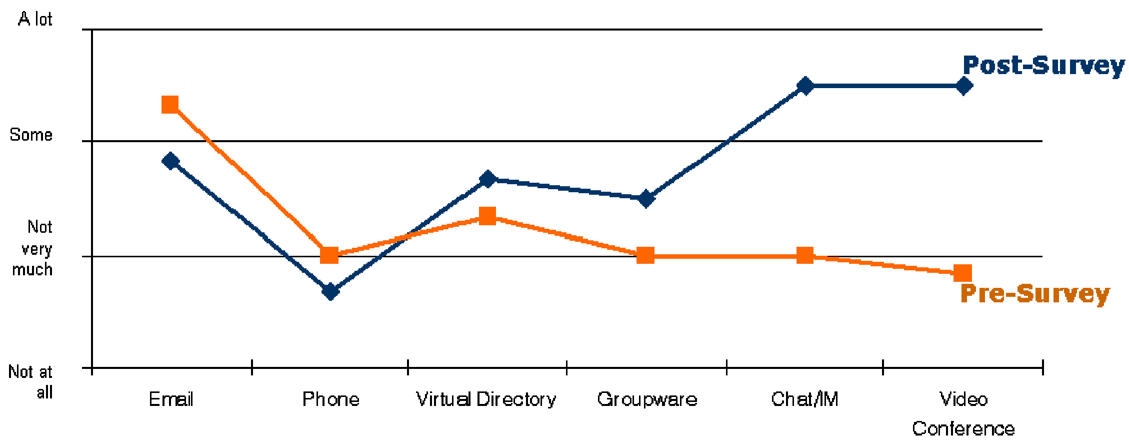


Figure 5.8 Perception of CMC technologies

Concerning software satisfaction, ten out of twelve student respondents believe that CMC technologies will be very effective tools for sharing tacit design knowledge. Data from the questionnaires was used to evaluate the software and to consider how the software could be improved and implemented in a distributed design environment. Table 5.4 shows students' answers regarding software satisfaction. Significance statistics are not reported for the data due to the small sample size.

Table 5.4 Number of answers from the post-experiment questionnaire

Very Enjoyable	1	2	3	4	5	6	7	Very frustrating
Overall, how would you describe your experience on the software?	2	2	2	0	0	0	0	
How would you describe your experience on the chat sessions?	2	2	2	0	0	0	0	
How would you describe your experience on the chat archives?	0	1	1	4	0	0	0	
Strongly Agree	1	2	3	4	5	6	7	Not at all
Overall, is the software well-designed to support sharing of design knowledge?	0	4	2	0	0	0	0	
Overall, do you think that the software is useful to improve your design project?	1	2	3	0	0	0	0	

Overall, all respondents reported that they would consider using the software for sharing design knowledge in their next design studio. Student perceptions of chat were very positive. On a scale of ‘Frustrating’ to ‘Very enjoyable,’ all students answered with favorable ratings. Most of them reported that their software experience was very enjoyable, and that the software is well-designed to support design knowledge sharing (Table 5.4). Students expressed that the chat sessions were very enjoyable, although some basic user interface issues had not yet been resolved (for example, screens were continuously refreshed and the chat thread could not be read.). However, these data indicate that participants were very satisfied with the functionality of the software in terms of knowledge sharing.

CHAPTER VI

CASE STUDY 3: HISTORIC BRYAN DOWNTOWN DESIGN STUDIO

Further observation on the exchange of tacit design knowledge in a distributed design environment was conducted in the third case study.

6.1 Settings

A third case study was conducted in an undergraduate level design studio at Texas A&M University, College Station, TX, during 2004. The design studio undertook a project for the historic downtown of the City of Bryan. The course objective was to generate architectural proposals responding to historical architectural context.

The studio instructor encouraged students to use the software as a substitute for weekly design critiques. Because this design studio was conducted during a summer semester, the class met every weekday. Consequently, by Friday the students are often very tired and stressed. To generate interest in Friday classes, the instructor set a side the Friday class time for students to talk via CMC technologies with design professionals, such as architects, city staffs, and engineers. The instructor urged students to discuss their design projects with the design critics every Friday. Because the students used CMC technologies to interact with the critics, they never had face-to-face meetings.

A plot in the historic downtown area was assigned to the students to be developed as a small commercial shop with residential functionality. The new building should be kept within the range of 4500 sq. ft. The shop could be designed according to a unique theme, such as a coffee shop, a pub, a bookstore, a casual wear shop, or a sporting goods shop. The students were asked to explore the possibility of linking residential and working activities, but at the same time they want to be able to keep a certain residential autonomy. The design of the residential area should incorporate features characterizing the profession of the owners. The residential area is composed of two two-bedroom units for rent. At the time of the experiment, the themes were already decided, and the students were in the conceptual design phase.

6.2 Participants

The participants for this case study were twelve undergraduate students completing the third year of a four-year Environmental Design program at Texas A&M University. Of these initial participants, seven students participated in real-time chat sessions while other five students just logged in at the chat sessions. The students who participated in the chat sessions completed the post-test questionnaire. None of the participants do have previous work experience as a designer or engineer in the industry. The participants' average age was 20 years. They have similar backgrounds but they have different attitude about knowledge acquisition and CMC technology. The researcher did not participate in the chat sessions except to answer technical questions and to help use the software.

The twelve students were divided into three groups. Since the project is located in historic downtown of the City of Bryan, the instructor was very careful to select guest critics with a great deal of previous experience in this area. One local architect and one city staff person were selected as design critics. Due to the difficulties of finding local design critics, one architect from Venezuela was selected as a design critic. He has in-depth knowledge on the design theories and space manipulation.

6.3 Data Collection and Analysis Methods

Overall data collection and analysis methods are identical to the second case study, the Peckerwood Garden case.

6.4 Procedures

Before the chat session began, students upload PDF versions of their conceptual drawings and model pictures for display in the chat session. They were also asked to fill out pre-experiment questionnaires. The design critics were asked to examine the design artifacts before each chat session. After conducting a one-hour training session, a 4-hour chat session was conducted in a strictly controlled computer lab environment. The students logged into the system at the same time and spent equal time in the system. The chat sessions were conducted in a computer lab equipped with Pentium IV computers with high-speed Internet connections, and a digital projector was used to demonstrate the software. The students then communicated in a chat room to discuss their design projects.

At the end of the semester, the students submitted and displayed their final posters in a gallery area at the College of Architecture. The posters were recorded to observe the differences incurred after the chat sessions. After the final review, the author sent a post-experiment questionnaire via email.

6.5 Findings

6.5.1 Findings from Content Analysis

Student 1

This case illustrates reuse of tacit knowledge during the chat session. Student 1 is a 21-year old female student majoring in Environmental Design program. She conducted a 10 minute online chat with a local architect who is a founding Principal in a local architectural design firm. The critic's primary expertise is architectural design and visualization technology. Since he has conducted numerous projects in the City of Bryan, he was able to give valuable suggestions about the site conditions and city regulations.

Within Student 1's project a small international coffee shop sits next to and beneath a bronze foundry and residential loft. The coffee shop specializes in gourmet coffees from around the world and also offers a selection of pastries and desserts. The coffee presentation is kept in the tradition of the country and culture from which it came, and her intention is that this unique atmosphere allows for the customer to experience a distinct cultural flavor yet feel as though they are part of a larger cultural diffusion.

When they started their conversation, the design critic asked Student 1 whether she read his comments to another student as follows:

> Critic 1: Did you read my comments to Barrett about the access issues?
>
> Student 1: Yes, I had originally had a lift for wheelchairs at the entrance on the empty space to the right.

As indicated in the excerpt above, the design critic wanted to give her the same comments about wheelchair accessibility in public spaces. All the students who have similar problems were able to fix their design artifacts according to the critic's comments, and she also revised her drawings at the end of the semester as shown in Figure 6.1.

Before

After

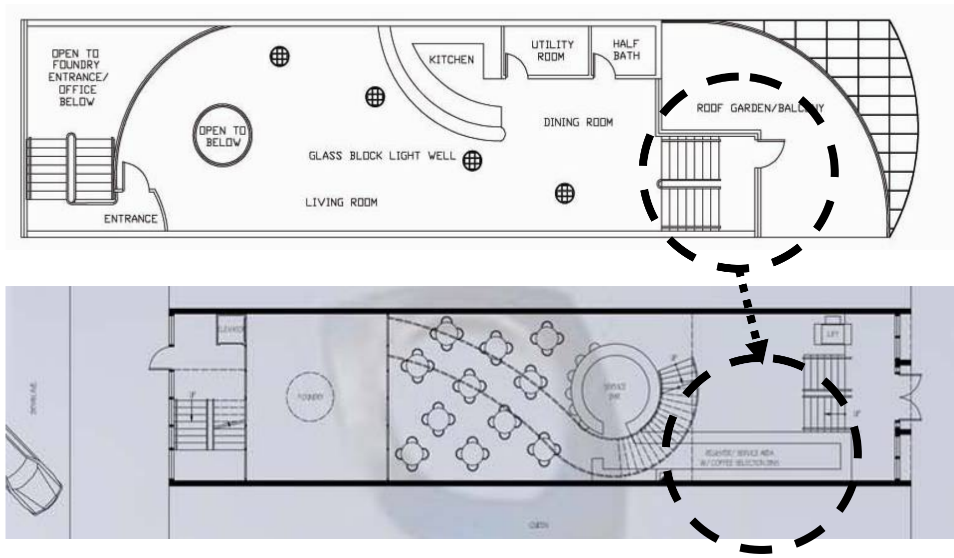


Figure 6.1 Student 1 revised example

<u>Student 2</u>

Student 2 is a 22-year old female majoring in Environmental Design. Her design critic is an architect working in Venezuela who received a Master of Architecture degree from the University of California, Berkeley. He is very familiar with design theory concepts, but because he has never visited the city of Bryan, he could not give comments about the local project's context. The majority of his comments are regarding design concepts, form and theory.

Student 2's project is a French bakery attached to a loft home where the residing family operates the business. This student wanted to create a "homey" atmosphere for the shop's patrons, but because the family resides above the bakery, she wanted to create and maintain a connection between the two spaces. A wood fired oven is the central feature used by both the bakery and family. A elemental curved form has been emphasized to create a soft, comfortable environment. The building facade reflects the curves occurring inside the space. The left side is a glass wall that allows passer-bys to see the oven from outside as an invitation to patrons. Her conceptual model was made of paper and green-color foam to emphasize the main idea of this project which is a wooden bakery oven (Figure 6.2).

Student 2 spent approximately fifteen minutes reviewing her design concepts with her critic. The critic rapidly conceived a problem with her project and readily made constructive comments to help her achieve more comprehensive design solution. At first her idea impressed the design critic. However, when he looked at her drawings (See Figure 6.2), he made the following comment:

Critic 2: when I see you model I see a strong idea, but when I see your drawings that strong idea almost vanishes.

Student 2: Well, the oven is definitely the main feature of my building.

Critic 2: The fireplace and the oven, both can be recognized from the inside as special elements and it serves as function and entertainment value.

Critic 2: CELEBRATE the elements!

Student 2 produced a revised section which reflected the suggestions from the critics, as shown in Figure 6.3.

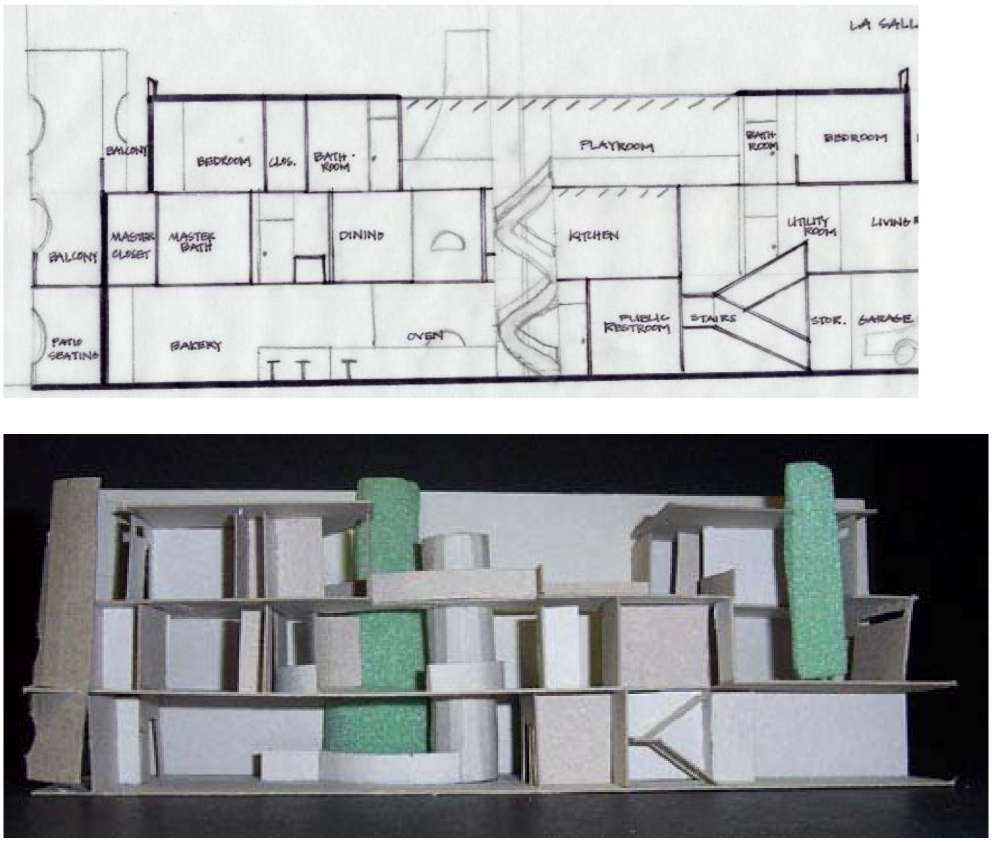


Figure 6.2 Student 2 section drawing & model picture (before the chat session)

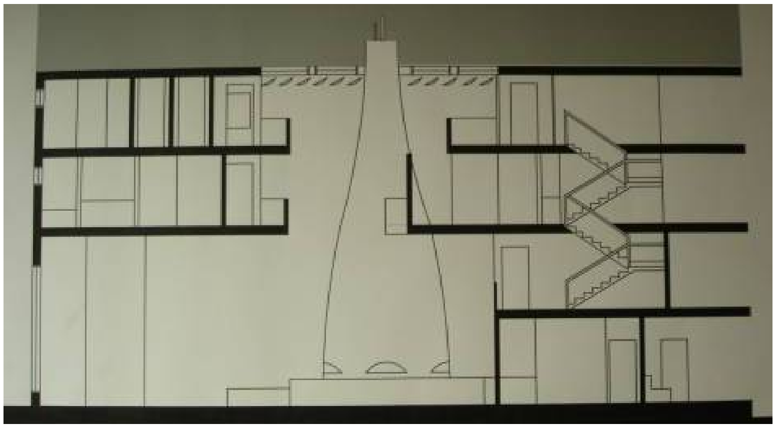


Figure 6.3 Student 2 revised section (after the chat session)

<u>Student 3</u>

The chat session for Student 3 was very short and straightforward. After a brief exchange of greetings, the critic pointed out inappropriate design elements on the front elevation. The critic suggested considering the existing design of the proposed building. During the final design stage, Student 3 changed the elevation as shown in Figure 6.4.

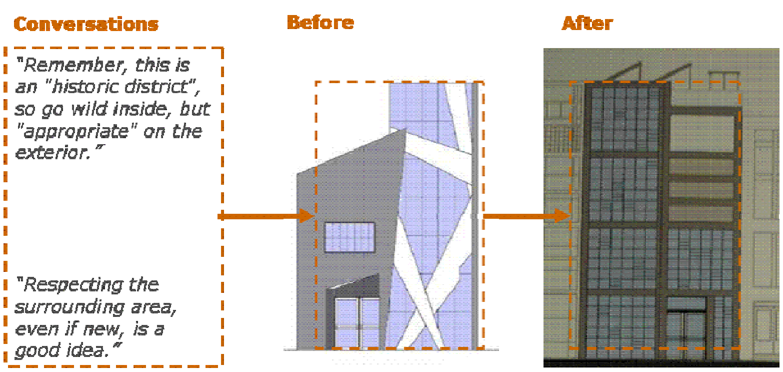


Figure 6.4 Student 3 revised example

CHAPTER VII

SUMMARY OF FINDINGS

7.1 Research Questions Revisited

The data presented and analyzed in the preceding chapters of this study have answered the research questions addressed in Chapter I as follows:

Research Question 1: What is the theoretical basis for the use of the software in a distributed design environment? The assumption behind this research is that advanced telecommunication systems provided by the Internet can be used successfully to convey tacit knowledge about architectural design. A review of literature and theory supports this assumption and helps define a theoretically attractive software environment of Internet-based chat that is enhanced by graphic and visualization tools, supported by a database system, and delivered through Web technology.

Research Question 2: How can the software assist in capturing and sharing experts' tacit knowledge? Protocol analysis of the chat transcripts showed that the chat sessions convey tacit knowledge. The answers from the surveys also demonstrate the ability of the software for the exchange of tacit design knowledge. Table 7.1 shows examples of chat messages of each category:

Table 7.1 Examples of chat messages from the second case study

Knowledge Type	Example
Tacit Knowledge	• Critic 1: and it also helps me to create the spaces by using solid diagonal axis. • Critic 2: the parking spaces at the inner part of the arc seem to be an afterthought and are not integrated with the median. • Critic 3: And keep in mind, that you can improve environmental friendliness one component at a time. Some things the owners demand, other things you can propose. Even green buildings are not ALL green. • Critic 4: I feel that maybe the center of the arch needs to be referenced / celebrated....
Explicit Knowledge	• Student 1: the louvers seen in the design of the roof are made of aluminum. • Critic 1: Excellent. I assume A&M is a member of the USGBC. Do you have access to their website, and access to LEED guidebooks? • Critic 1: Is "Natural Capitalism" required reading there yet? • Student 2: All the walls will be varying textures of stucco, some heavy, some lighter
Other	• Student 3: On slide 3, you may see the bigger first floor plan. • Student 2: The walls are framing each space of my Meeting center.

Students in the second and third case studies reported their use of the software by answering questions in the post-experiment questionnaire. The students' perception indicated that the chat sessions are very helpful in improving their design projects. They would consider using the software for sharing design knowledge in their next design studio. Participants had clear expectations that synchronous chat could be integrated with visual display, such as "mark-up systems". Figure 7.1 shows a comparison of the students' perception on the use of the software: overall satisfaction on the chat sessions, functionality of the software, overall satisfaction on the software, usefulness in design improvement, and satisfaction with the chat archives.

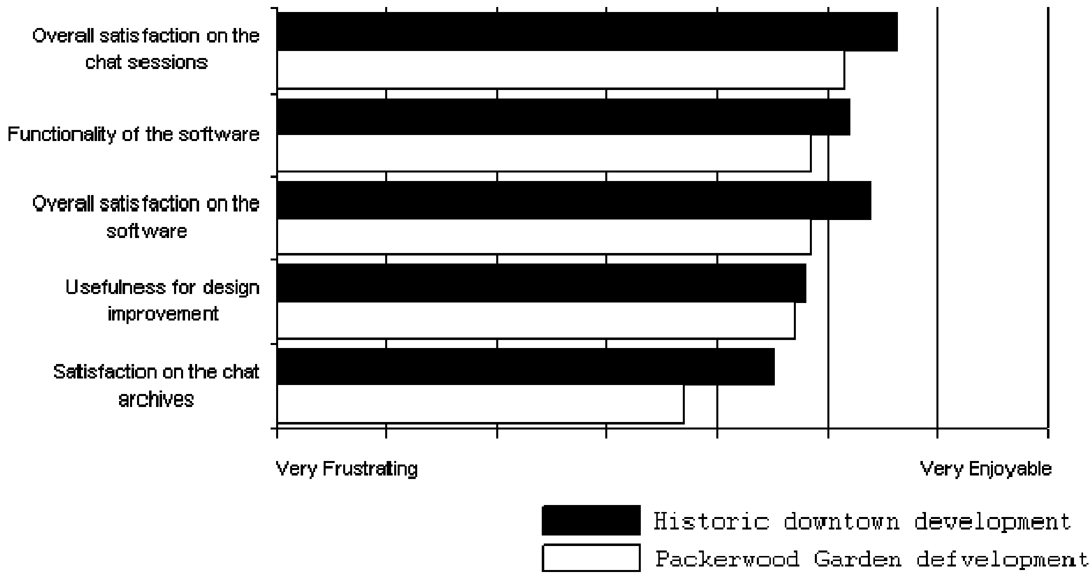


Figure 7.1 Students' perception on the use of the software from the second and third study

In many instances, design solutions proposed by design critics were conveyed to other students because they participated in the same chat conversations at the same time.

In the third case study, the instructor was very pleased with the results from the chat session, and he distributed a copy of the chat transcript as a class reference to allow his students to read the conversation as needed. Since the students were conducting projects in the same area, the comments from the experienced architects were judged to be very useful for every student.

<u>Research Question 3: Is tacit knowledge shared through online conversations evident in student design artifacts?</u> In many instances, the students' design artifacts result in design

improvement. Content analysis of the students' design artifacts shown in Chapters IV, V, and VI clearly and repeatedly indicated that reuse is evident in the majority of the students design artifacts. Additionally, there were many comments from the participants showing the evidence of distinctive improvements in their design performance. These studies also support the conclusion that the students showed substantial design improvement from reusing the tacit design knowledge fed to them from the professionals.

Research Question 4: What are the factors that influencing the effective use of the software? In analyzing the data obtained from both case studies, there are some important factors that could increase or decrease the use of CMC technologies in a distributed design environment. Tables 7.2 and 7.3 show the comparison on the factors for the participants from the second case study.

Table 7.2 Comparison of the participants from the second case

	Knowledge Gathering attitude	**Expertise matching**	**Timing of the communication**	**Design improvement**
Student 1	Highest (3.2 out of 4 Likert scale)	Yes. Professional recommendation on the ceiling design provided	Late	Ceiling design changed
Student 2	Highest (3.2 out of 4 Likert scale)	Yes. Significant design problems identified	Late	Problem fixed
Student 3	Medium (2.25 out of 4 Likert scale)	No. the student did not like the recommendation	Late	No changes
Student 4	Lowest (1.8 out of 4 Likert scale)	Yes. The student liked the recommendation	Late	No changes

Table 7.3 Comparison of the participants from the third case

	Knowledge Gathering attitude	Expertise matching	Timing of the communication	Design improvement
Student 1	Medium (2.8 out of 4 Likert scale)	Yes. Professional recommendation on the ADA compliances provided	Early	Lamp design changed
Student 2	Highest (3.2 out of 4 Likert scale)	Yes. Professional recommendation on the design concepts provided	Early	Building section changed
Student 3	Medium (2.8 out of 4 Likert scale)	Yes. Professional recommendation on the building elevation design provided	Early	Elevation design changed

The first important factor is the students' "knowledge gathering attitude." The findings of both case studies indicate that students with a higher knowledge gathering attitude reuse more tacit design knowledge than students with a lower knowledge gathering attitude.

A second important factor is "timely expertise matching." Design critic's knowledge of the project is always an important factor in design critique sessions. Often, the knowledge is tied closely to the design concepts and requirements. Likewise, in all three case studies, the online chats are reflective conversation of the situation. Since the students want to gather specific tacit design knowledge exclusively for their own projects, the knowledge should be collectively applied to the students' projects. This is the reason why the concept of knowledge mapping could facilitate comprehensive knowledge creation in the AEC industry.

In the third case study, a city staff member was invited to the chat session, but he was not familiar with the distributed design studio settings. His answers were so naive; therefore he did not make any significant impacts on students' design projects. One student who talked with the city staff stated that:

> Very confused, especially if you are talking to a person who does not understand the context of the project.

The third important factor is the "timing of the communication". The results of this research also support those of Cheng and Kvan (2000)'s study, which studied design collaboration strategies in virtual design studios. The knowledge must be shared at the right time. Since the first case study was conducted during the late stage of the design project, students' design project had been already matured. Several reviewers pointed out that participation would have been greater and the measurable contribution could have been much greater, if the design projects had begun using this interface in the earlier stage. The maturity of the projects discussed in the chat sessions was the major barrier to this case study.

In the second case study, the experiments were conducted in the very early stage of the project so that the students had plenty of time to apply their new knowledge to the project. Of course it is easier to incorporate changes during the early phases of the project.

7.2 Comparison of the Case Studies

Comparisons between the three case studies in the design studios are drawn in this chapter. The remarkable thing about these case studies is the similar results based on the exchange of tacit design knowledge, despite the differences in the participants and case settings (Table 7.4). Given the data presented above, it is clear that tacit knowledge could be shared and captured by CMC technologies and can enhance student design performance by giving a more comprehensive communication space in which experts provide tacit knowledge as well as task-related guidance and encouragement. Of course, there are striking differences caused from influences CMC usage. This research indicates that the exchange of tacit design knowledge is heavily dependent upon situational factors.

The first case study, the NASA design studio, shows that the novelty of experts' knowledge might be an important factor in increasing the exchange of tacit knowledge. The participants all showed a very good knowledge gathering attitude because the NASA professionals provided very exclusive knowledge to the participants. The second case study shows the importance of timing of the communication. The third case study shows the importance of expertise matching.

Table 7.4 Communication media for the studies

	CMC	Physical Meeting	No. of Students
NASA restraint system development	Chat Session, Class Website	No	26
Peckerwood Garden development	Chat Session	Yes	12
Historic downtown development	Chat Session	Yes	12

7.3 Theoretical Model Development

The initial theoretical framework was modified and extended as a theoretical model for the design knowledge sharing process by formulating the research results (Figure 7.2). Design knowledge sharing is initiated by applying ‘generalized tacit design knowledge’ to a specific design problem. When the students talked with their design critics to acquire tacit design knowledge, the design critic’s generalized tacit design knowledge may become ‘specific tacit design knowledge’ with the consideration of a specific design problem.

The students then convert specific tacit design knowledge into explicit formats, such as sketches, models, and drawings. Although these explicit expressions are often inadequate to fully articulate tacit design knowledge, it is a typical process of reflective practice in the design profession (Schön 1983). Students then produce a design solution and update their ‘generalized explicit design knowledge’. Finally, what they experienced are converted and accumulated as ‘generalized tacit design knowledge’ in the form of a shared mental model or technical know-how (Nonaka and Tacheuchi 1995).

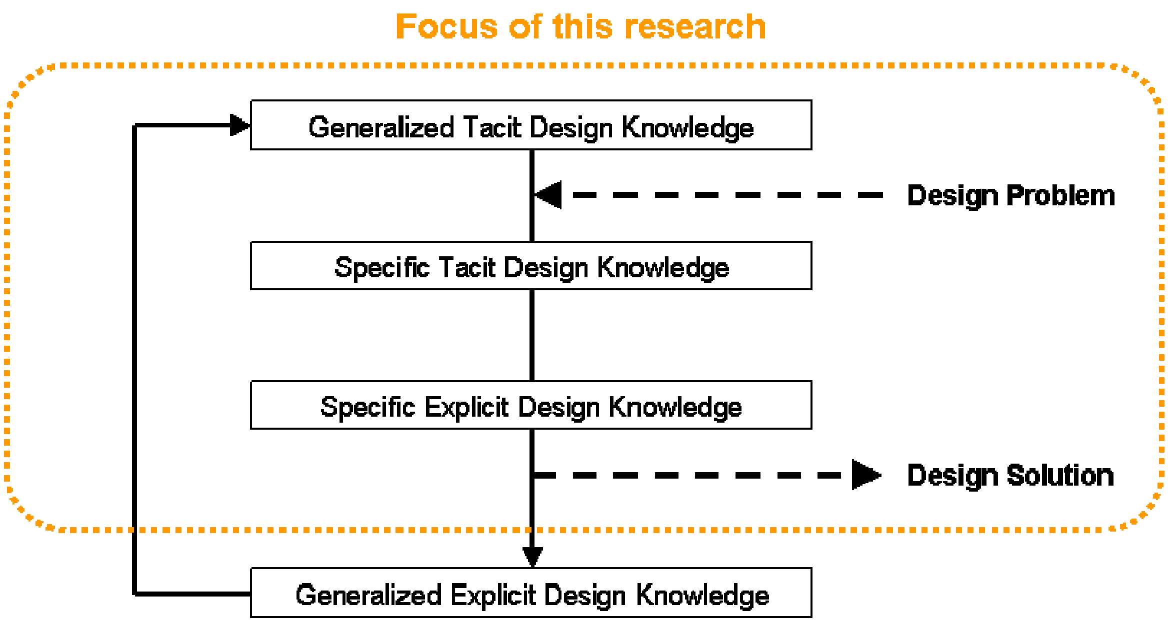


Figure 7.2 Theoretical model development

CHAPTER VIII

CONCLUSIONS

8.1 Contributions

The first contribution of this research is the growth of our level of understanding about the implications of the exchange of tacit design knowledge. Schön (1983) demonstrated that there should be many benefits of capturing, storing, and reusing architects' tacit design knowledge. Nevertheless, the observed practice is that many architectural firms prefer to make knowledge explicit and store it as computer software and databases. This research presented here strengthens Schön's (1983) claim about knowledge reflection in design studios by providing empirical evidence regarding tacit knowledge sharing.

The second contribution of this research is the suggestion of the use of CMC strategies in a distributed design environment. Particularly, these results show that the use of synchronous chat sessions positively influences design performance by sharing and reusing tacit design knowledge. The answers from the surveys also indicate that the students' perception about the software is very positive. Most students would consider using the software for sharing design knowledge in their next design studio.

This research also indicates that tacit design knowledge can be confidently shared and reused through careful strategic implementation in a distributed design environment. Content analysis and demographic and attitudinal participant surveys suggest that enabling factors for sharing tacit design knowledge include a knowledge sharing attitude, timing of the communication, timely expertise matching, CMC technology support, and a higher sense of cohesion. Strong management support and commitment from leadership can also provide for a positive knowledge sharing experience.

The third contribution of this research is the development of a new software testing method that provides increased validity by combining and extending content analysis methods, protocol analysis, the Charrette Test method (Clayton et al. 1998), and software usability testing (Neilsen 1993). A literature review indicates that previous software research for architectural design has focused on providing theoretical frameworks or limited quantitative measurements based on limited trials. The research methods used here provide increased validity on the effectiveness of the software by providing multiple evidence and greater in-depth descriptions of design artifacts.

8.2 Originality

This research has developed a method through which AEC organizations can extract valuable tacit knowledge directly from employees and apply those assets to the work processes. Consequently, higher performance levels can theoretically be achieved by accelerating knowledge transfer processes.

The originality of this research lies in recognizing the significance of the tacit design knowledge contained in design communications in a distributed design environment. Many researchers have undertaken studies concerning the potential of CMC technologies to support architectural design processes in a distributed design environment. However, their research has rarely explored how experts' knowledge affects student design performance and thus is not identical to any of them.

Previous research has rigorously shown that the use of CMC technologies can indeed facilitate design communication in a distributed design environment (Cheng and Kvan 2000; Gabriel and Maher 1999; Kvan and Candy 2000). Few researchers have also evaluated whether the differences in communication media have an effect on the quality of the completed architectural design using statistical analysis.

The methodology used in this research is different from the earlier studies in that is uses statistical methodologies. Rather than inviting faculty members to participate as design critics, the design critics in these studies were selected from architectural firms and the USGBC (The United States of Green Building Council) because they provide in-depth insight into realistic knowledge sharing process in a distribute design environment.

8.3 Generality

These case studies were conducted with design critics who work in the real world. Two design studios had actual clients receiving the proposed solutions. Furthermore, the design studios contained all of the resemblance of professional design activities. These studies build examples of practice and critical reflection through the core experience of learning architectural design.

8.4 Limitations

The analysis of some responses from open-ended questions revealed improvements that can be made in the software to create more comprehensive design knowledge communications. Several reviewers pointed out that participation would have been greater and the measurable contribution could have been much greater, if the design project had begun using this software in the earlier stage. The maturity of the projects discussed in the chat sessions was a major barrier of one particular case study. There were a few suggestions on the time schedule for the chat sessions. The participants describe as being useful but found it difficult to arrange timely chat schedules. They prefer to schedule more chat sessions with longer time frames to form a more cohesive group. Student participants felt that the reviewers need to be given more time to understand the history and background of the projects.

8.5 Future Research

The findings of this research led to a proposition that will direct future research as follows:

Synchronous chat may be a tool that can be used to help architects collaborate on design works in a distributed design environment. The chat scripts are especially useful because they can remind participants of the discussion topics and information contained therein. The records of dialogue are the most significant tacit knowledge resource to the students for reviewing. Because of this, a method for capturing knowledge should be developed in the future. When professionals handle knowledge of high value, they intuitively want to capture it, but often they cannot spend adequate time to capture and store it appropriately. As professionals leave an organization, their knowledge also leaves, therefore organizations should extract, reflect and retain experts' tacit knowledge within organizational boundaries.

REFERENCES

Al-Qawasmi, J. 1999. A study of computer-mediated, collaborative architectural design, Ph.D. dissertation, Texas A&M University, College Station, TX.

Ambrosini. V., and C. Bowman. 2001. Tacit knowledge: Some suggestions for operationalization. *Journal of management studies*. 38 (6): 811-829.

Atman. C., J. Chimka, K. Bursic, and H. Machtmann. 1999. A comparison of freshmen and senior engineering design processes. *Design Studies*. 20: 131-152.

Baumard, P. 1999. *Tacit knowledge in organizations*. London: Sage Publications.

Bridges, A. 1997. Implications of the Internet for the construction industry. *Automation in Construction*. 6: 45-49.

Brown, J., and P. Duguid. 1991. Organizational learning and communities-of-practice: toward a unified view of working, learning, and innovation. *Organization Science*. 2 (1): 40-57.

Casakin, H., and G. Goldschmidt. 1999. Expertise and the use of visual analogy: Implications for design education. *Design Studies*. 20 (2): 153-175.

Cheng, N., and T. Kvan. 2000. Design collaboration strategies. In *Proceedings of SIGRADI 2000,* 45-49. Rio De Janeiro, Brazil.

Clayton, M., J. Kunz, and M. Fischer. 1998. The Charrette Test method. CIFE Technical Report #120. Palo Alto, CA: Stanford University.

Constructware. 2005. A Constructware white paper. Available at http://www.Constructware.com.

Cross, N. 2000. *Engineering design methods: Strategies for product design*. 3rd ed. New York: John Wiley & Sons.

Cross, N., H. Christiaans, and K. Dorst. 1996. *Analysing design activities*. New York: John Wiley & Sons.

Cross, N., and A. Cross. 1995. Observations of teamwork and social processes in design. *Design Studies*, 16: 143-170.

Davenport, T., and L. Prusak. 1998. *Working knowledge: How organizations manage what they know*. Boston: Harvard Business School Press.

Dennis, A., and J. Valacich. 1999. Rethinking media richness: towards a theory of media synchronicity. In *Proceedings of the 32nd Hawaii International Conference on System Sciences (HICSS'99)*, 1017-1027. Kauai, HI.

Denzin, N., and Y. Lincoln. 1994. *Handbook of qualitative research*. Thousand Oaks, CA: Sage Publications.

Dixon, N. 2000. Common *knowledge: How companies thrive by sharing what they know*. Boston: Harvard Business School Press.

Dorst, K., and N. Cross. 2001. Creativity in the design process: Co-evolution of problem-solution. *Design Studies*. 22: 425-437.

Feigenbaum, E. 1992. A personal view of expert systems: Looking back and looking ahead. Knowledge Systems Laboratory Report No. KSL 92-41, Palo Alto, CA: Stanford University.

Fruchter, R., and P. Demian. 2002. CoMem: Designing an interaction experience for reuse of rich contextual information from a corporate memory. *AIEDAM 2002.* 16: 127-147.

Gabriel, G., and M. Maher. 1999. Coding and modeling communication in architectural collaborative design. *In Proceedings of the ACADIA '99*, 152-166. Salt Lake City, UT.

Gall, M., W. Borg, and J. Gall. 1996. *Educational research*. 6th ed. White Plains, NY: Longman Publishers.

Gero, J., and T. McNeill. 1998. An approach to the analysis of design protocols. *Design Studies*. 19: 21-61.

Gilmour, D. 2003. How to fix knowledge management. *Harvard Business Review*. 81(10): 16-17.

Hansen, M., N. Nohria, and T. Tierney. 1999. What's your strategy for managing knowledge. *Harvard Business Review*. 77 (2): 106-116.

Herring, S. 1996. *Computer-mediated communication: Linguistic, social and cross-cultural perspectives*. Amsterdam: John Benjamins.

Herschel, R., H. Nemati, and D. Steiger. 2001. Tacit to explicit knowledge conversion: Knowledge exchange protocols. *Journal of Knowledge Management*. 5 (1): 107-116.

Ho, C. 2002. Personal Communication, Texas A&M University, College Station, TX.

Huang, J. 1999. Knowledge sharing and innovation in distributed design: Implications of Internet-based media on design collaboration. *International Journal for Design Computing, Proceedings of DCNet '99*. Available at http://www.arch.usyd.edu.au/kcdc/journal/vol2/dcnet/sub5.

Isaacs, E., A. Walendowski, S. Whittaker, D. Schiano, and C. Kamm. 2002. The character, functions, and styles of instant messaging in the workplace. In *Proceedings of the CSCW'02*, 126-135. New Orleans, LA.

Johannessen, J., J. Olaisen, and B. Olsen. 2001. Mismanagement of tacit knowledge: The importance of tacit knowledge, the danger of information technology, and what to do about it. *International Journal of Information Management*. 21: 3-20.

Johnson R., and M. Clayton. 1998. The impact of information technology in design and construction: The owner's perspective. *Automation in Construction*. 8: 3-14.

Kankanhalli, A., F. Tanudidjaja, J. Sutanto, and B. Tan. 2003. Role of Information Technology in Successful Knowledge Management Initiatives. *Communications of the ACM*. 46 (9): 69-73.

Kvan, T., and L. Candy. 2000. Designing collaborative environments for strategic knowledge in design. *Knowledge-Based Systems*. 13 (6): 429-438.

Laepple, E., M. Clayton, R. Johnson, and S. Parshall. 2005. Content analysis of web-based collaboration design: empirical evidence of design process. In *AIA Report on University Research 2005*, 104-117. edited by D. Friedman and F. Hoermann. Bloomington, IN: Original Smith Printing.

Levitt, R., and J. Kunz. 1985. Using knowledge of construction and project management for automated scheduling updating. *Project Management Quarterly*. 16 (5): 57-76.

Malhotra, Y. 2000. *Knowledge management and virtual organizations*. Hershey, PA: Idea Group Publishing.

Nakane, J., and S. Meza. 2001. Creating new competitive advantage through Ba. *Target*. 17 (2): 6-14.

Neilsen, J. 1993. *Usability engineering*. Boston: Academic Press.

Nonaka, I., and H. Takeuchi. 1995. *The knowledge creating company*. New York: Oxford University Press.

O'Hara, K., and B. Brown. 2001. Designing CSCW technologies to support tacit knowledge sharing through conversation initiation. In *ECSCW'2001*. Bonn, Germany. Available at http://www.appliancestudio.com/publications/external/tacitkwwkshpn.pdf.

Polanyi, M. 1966. *The tacit dimension*. Garden City: Doubleday.

Reber, A. 1993. *Implicit learning and tacit knowledge: an essay on the cognitive unconscious*. New York: Oxford University Press.

Ribak, A., M. Jacovi, and V. Soraka. 2002. Ask before you search: pear support and community building with ReachOut. In *Proceedings of the Computer Supported Cooperative Work'02,* 126-135. New Orleans, LA.

Roe A. G., and M. Phair. 1999. Connection crescendo. *Engineering News Record*. 242 (19): 22-29.

Rogus, D. 2001. Collecting your thoughts. *Constructech*. Available at http://www.constructech.com/printresources/v4n6025.htm.

Sachs, P. 1995. Transforming work: Collaboration, learning, and design. *Communications of the ACM*. 38 (9): 36-44.

Sancar, F. 1996. Behavioural knowledge integration in the design studio: an experimental evaluation of three strategies. *Design Studies*. 17: 131-163.

Schön, D. 1983. *The reflective practitioner: How professionals think in action*. New York: Basic Books.

Skaggs, R., 2002. One foot firmly planted, we're still climbing. *Rowlett Distinguished Firm Lecture Series 2000*. College Station, TX: CRS Center.

Somech, A., and R. Bogler. 1999. Tacit knowledge in academia: its effects on student learning and achievement. *The Journal of Psychology*. 133 (6): 605-616.

Spencer, D., and S. Hiltz. 2002. A field study of use of synchronous chat in online courses. In *Proceedings of the 36th Hawaii International Conference on System Sciences (HICSS'O3),* 36-46. Kauai, HI.

Stake, R. 1995. *The art of case study research*. Thousand Oaks, CA: Sage Publications.

Stenmark, D. 2000. Leveraging tacit organizational knowledge. *Journal of Management Information Systems*. 17 (3): 9-24.

Sternberg, R., G. Forsythe, J. Hedlund, J. Horvath, R. Wagner, W. Williams, S. Snook, and E. Grigorenko. 2000. *Practical intelligence in everyday life*. New York: Cambridge University Press.

Suwa, M., T. Purcell, and J. Gero. 1998. Macroscopic analysis of design processes based on a scheme for coding designers' cognitive actions. *Design Studies*. 19: 455-483.

Sveiby, K. 1997. *The new organizational wealth*. San Francisco: Berrett-Koehler Publishers.

Valkenburg, R., and K. Dorst. 1998. The reflective practice of design teams. *Design Studies*. 19: 249-271.

Visser, W. 1995. Use of episodic knowledge and information in design problem solving. *Design Studies*. 16: 171-187.

Wesek, J., V. Cottrez, and P. Landler. 2000. A benefits analysis of online project collaboration tools within the architecture, engineering and construction industry. Technical report, Available at http://www.pwcglobal.com.

Zack, M. 1999. Managing codified knowledge. *Sloan Management Review*. 40 (4): 45-58.

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